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SLUDGE

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This manual represents the state-of-the-art on process design for municipal sludge land application systems. It is the third in a series to serve as an update of the October 1974 Process Design Manual for Sludge Treatment and Disposal (EPA 625/1-74-006). The first two volumes in the series were Municipal Sludge Landfills, EPA 625/1-78-010, and Sludge Treatment and Disposal, EPA 625/1-79-0011. Preparation of this manual was sponsored by the U.S. Environmental Protection Agency's Municipal Environmental Research Laboratory (MERL) and the Office of Water Program Operations (OWPO). A coordinating committee assisted EPA and its contractor in defining the scope and content of this effort, guided the work of the contractor, and was responsible for coordinating technical reviews of the manual. A group of very responsive technical experts and invited reviewers from the private sector, academic institutions, and state and federal agencies provided many helpful technical review comments. Contract administration was provided by EPA MERL, Cincinnati, Ohio.

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CHAPTER 1

INTRODUCTION

1.1 General

Land application of municipal wastewater treatment plant sludge can be managed in a cost-effective and environmentally safe manner. Estimates made in 1980, shown in Table 1-1, indicate that approximately one quarter of the sludge generated in the United States was being directly utilized for landspreading on food chain and non-food chain cropland. Since much of the sludge marketed or distributed free also goes to the land, the total may approach 40 percent. Increased numbers and capacities of wastewater treatment facilities, constraints on many sludge disposal alternatives, and increasing costs have led many additional communities to consider use of land application techniques. As shown in Table 1-1, smaller publicly owned treatment works (POTW's) tend to use land application more than do large POTW's. As shown in Table 1-2, the estimated sludge production in 1982 was almost 7,000,000 dry tons; this quantity is expected to increase in the future.

1.2 Historical Perspective of Options

Land application of sewage and sludge has been practiced in many countries for centuries. Many "sewage farms" were initiated as a preferred alternative to the direct discharge of raw sewage into waterways. A large number of land application projects have involved the use of sewage or sludge on agricultural land (and a few on land dedicated to the disposal of sludge), relatively few long-term projects have been developed where sludge or sludge compost has been used on forested lands, or to reclaim drastically disturbed lands.

1.3 Objectives of Manual

The principal objective of this manual is to provide general guidance and basic information for use in planning, designing, and operating projects for land application of sludge by one or more of the following design options:

- Agricultural utilization.
- Forest land utilization.
- Drastically disturbed land utilization.
- High-rate dedicated land disposal site, other than landfills.

Certain alternative land application options, such as biomass production of trees or other crops for fuel or conversion to ethanol, are not discussed in detail, because they are emerging technologies, and insufficient data exist to select design parameters, evaluate costs, and draw conclusions. The techniques for preliminary sludge treatment and processing (i.e., digestion, composting, disinfection, dewatering, etc.) are described in other sources (1) (2), and are not included herein.

TABLE 1-1
ESTIMATED DISTRIBUTION OF MUNICIPAL SLUDGE IN 1980, BY MANAGEMENT METHOD AND TREATMENT PLANT SIZE*

	Percent of Sludge Managed by This Method by Plant Size			
Management Method	Small <1 mgd	Medium 1-10 mgd	Large 10 mgd	Percent of Total
Landspreading on food chain crops	31	22	10	12
Landspreading on non-food chain crops	8	17	11	12
Distribution and marketing	11	13	19	18
Landfill	31	35	12	15
Thermal processing, e.g., incineration	1	1	32	27
Ocean disposal	1	0	4	4
Other, e.g., long-term lagooning	17	12	12	12
Total	100	100	100	100

* Based upon data supplied by the U.S. EPA Sludge Task Force, 1983.

TABLE 1-2
ESTIMATED MUNICIPAL SLUDGE PRODUCTION IN 1982, BY POTW SIZE*

POWT Size (MGD)	No. of POTWs	Sludge Produced (dry tons/yr)	Percent of Total
0-2.5	14,168	1,189,810	17
2.5-5	631	515,504	8
5-10	352	588,445	9
10-20	187	622,478	9
20-50	125	924,896	14
50-100	40	676,091	10
100	41	2,324,274	34
Total	15,544	6,843,493	

* Based upon analysis of data from the 1982 Needs Survey supplied by the U.S. EPA Sludge Task Force, 1983.

1.4 Scope of Manual

This manual represents the state of the art with respect to land application of sludge for its use in agriculture, forestry, land reclamation, and high-rate dedicated land disposal. Previously published EPA manuals which should be extensively used as supplemental information sources are:

- Process Design Manual - Municipal Sludge Landfills (EPA-625/1-78-010), Reference (1).
- Process Design Manual - Sludge Treatment and Disposal (EPA-625/1-79-011), Reference (2).
- Process Design Manual for Dewatering Municipal Wastewater Sludge (EPA-625/1-82-014), Reference (3).

References are made throughout this manual to these documents.

1.5 Use of Manual

The information contained in this manual is intended for use by municipal wastewater treatment and sludge management authorities, project planners, designers, and consultants in many disciplines including engineering, soil science, agronomy, etc.

Figure 1-1 presents a suggested sequence to follow when using this manual. This sequence may be varied according to user needs. Chapter 2 provides an overview of land application options and the advantages/disadvantages of each option. Chapter 3 discusses public participation. Chapter 4 covers the primary elements needed for technical assessment and preliminary project planning. Chapter 5 provides detailed site evaluation and selection procedures; and selection of the final land application option or options. After an option or a combination of options is selected, the process design chapters (Chapters 6 through 9) relevant to the option(s) selected should be consulted. Chapters 10 and 11 provide general facility design and O&M guidance. Appendices A, B, and C provide supplemental data and information which may be useful to some manual users. Appendices D and E provide two case studies.

1.6 References

1. U.S. EPA. Process Design Manual: Municipal Sludge Landfills. EPA 625/1-78-010. (Available from National Technical Information Service, Springfield, Virginia, PB-279 675). October 1978.

2. U.S. EPA. Process Design Manual for Sludge Treatment and Disposal. EPA 625/1-79-011. MERL, ORD, Washington, D.C. September 1979.

3. U.S. EPA. Process Design Manual for Dewatering Municipal Wastewater Sludge. EPA-625/1-82-014. MERL, ORD, Washington, D.C. October 1982.

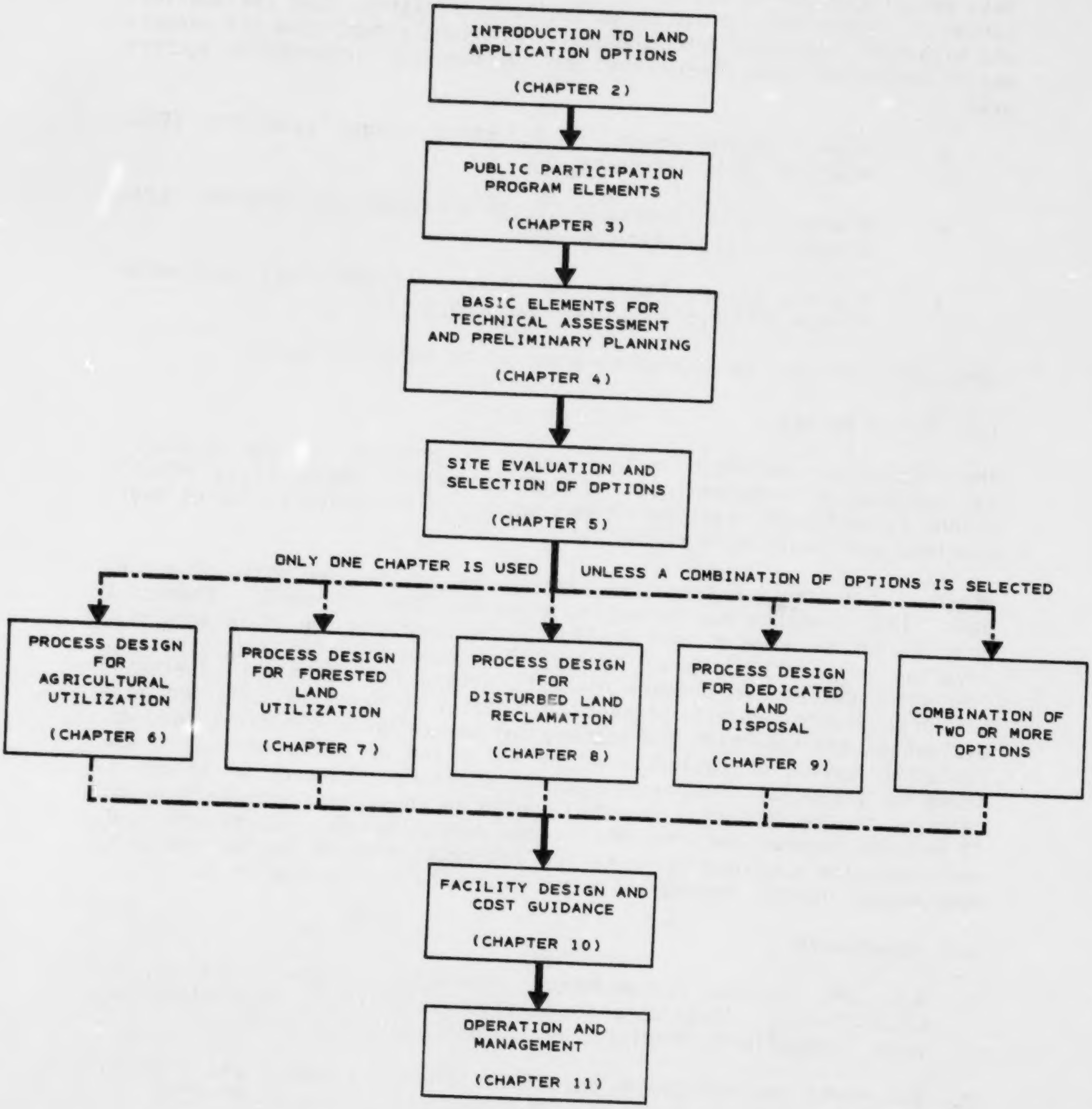
INTRODUCTION TO LAND APPLICATION OPTIONS
(CHAPTER 2)
PUBLIC PARTICIPATION PROGRAM ELEMENTS
(CHAPTER 3)
BASIC ELEMENTS FOR TECHNICAL ASSESSMENT AND PRELIMINARY PLANNING
(CHAPTER 4)
SITE EVALUATION AND SELECTION OF OPTIONS
(CHAPTER 5)
ONLY ONE CHAPTER IS USED
UNLESS A COMBINATION OF OPTIONS IS SELECTED
PROCESS DESIGN FOR AGRICULTURAL UTILIZATION
(CHAPTER 6)
PROCESS DESIGN FOR FORESTED LAND UTILIZATION
(CHAPTER 7)
PROCESS DESIGN FOR DISTURBED LAND RECLAMATION
(CHAPTER 8)
PROCESS DESIGN FOR DEDICATED LAND DISPOSAL
(CHAPTER 9)
COMBINATION OF TWO OR MORE OPTIONS
FACILITY DESIGN AND COST GUIDANCE
(CHAPTER 10)
OPERATION AND MANAGEMENT
(CHAPTER 11)

Figure 1-1. Sequence of the manual's use.

CHAPTER 2

OVERVIEW OF SLUDGE APPLICATION OPTIONS

2.1 Introduction

The sludge application options covered in this manual are:

- Agricultural Utilization: Use of sludge as a source of fertilizer nutrients and/or as a soil amendment to enhance crop production. Effectiveness of sludge as a soil amendment generally requires application rates greater than agronomic rates (e.g., the nutrient requirement of the crop).
- Forest Utilization: Use of sludge on forested land to enhance forest productivity.
- Land Reclamation Utilization: Application of sludge to strip mine lands, mine tailings, or other disturbed or marginal land for the purpose of revegetation and reclamation.
- Dedicated Land Disposal (DLD): Application of sludge to soils, with or without vegetation, for the primary purpose of sludge disposal. This option differs from the others in that sludge is generally applied at higher rates and system management is more intensive. Crop production (if any) is of secondary importance. Specifically excluded from the DLD site definition used herein are landfills, i.e., sites where sludge or sludge mixed with refuse, is deeply buried, and covered.

The definitions above are not mutually exclusive. For example, land reclamation utilization may involve the planting of trees on the sludge-amended soil; or a dedicated land disposal site may produce agricultural crops, etc. It is also possible that two or more options, e.g., agricultural and forest utilization, can be used in a single sludge management program. Table 2-1 summarizes the typical characteristics of the sludge-to-land options covered in this manual.

Each of these options has advantages and disadvantages in terms of the quality and quantities of sludge that can be utilized and for application site requirements. This chapter provides an overview of these options and highlights their advantages and disadvantages. Each option is then discussed in much greater detail in the subsequent design chapters. These design chapters present the criteria and limitations that establish the sludge application rates:

- Chapter 6, Agricultural Application, is designed for the N and/or P need of the crop. This is to ensure acceptance by

TABLE 2-1
SUMMARY OF TYPICAL CHARACTERISTICS OF ALTERNATE SLUDGE-TO-LAND OPTIONS

Characteristics	Agricultural Utilization	Forest Land Utilization	Land Reclamation Utilization	Dedicated Disposal Site
Sludge Application Rates	Varies; normal range in dry weight of 2 to 70 mt/ha (1 to 30 T/ac)/yr depending on type of crops, sludge characteristics, etc.	Varies; normal range in dry weight of 10 to 220 mt/ha (4 to 100 T/ac)/yr depending on soil, tree species, sludge quality, etc. One-time application may be at higher rates.	Varies; normal range in dry weight of 7 to 450 mt/ha (3 to 200 T/ac)/yr. Usually a one-time application.	Varies; normal range in dry weight of 220 to 900 mt/ha (100 to 400 T/ac)/yr depending on soil, climate, etc.
Sludge Application Frequency	Typically repeated annually, usually scheduled between harvesting and planting. Scheduling can be complex with large system.	Often just a one-time application. Additional applications at 1- to 5-year intervals.	Usually a one-time application. Additional applications at 5- to 10-year intervals.	Varies; when climate is suitable, applications every 5 to 20 days are routine.
Ownership of Application Site(s)	Usually privately owned land. Condition of sludge application often covered by a contract between farmer(s) and municipality.	Usually owned by private land owner tree growing firm or governmental agency at state/federal level.	Usually owned by mining firm or governmental agency at state/federal level.	Usually owned by municipalities generating/disposing of sludge or controlled under a long-term lease.
Useful Life of Application Site(s)	Limited by accumulated metals loadings from total sludge applied. With most sludges, a useful life of 5 to 20 years or more is normal.	May be limited by accumulated metal loading in total sludge applied. With typical sludge, a useful life of 5 to 20 years or more is normal.	Usually a one-time application. Municipality(ies) must plan to arrange for sequence of additional sites in future years.	Theoretically there is no limit to useful life of properly designed site. Very common that land used cannot be used in future for agriculture.
Sludge Transport Complexity and Cost	Can be expensive if farms are numerous and widespread. Scheduling can be difficult, because sludge applications must work around planting/harvesting/weather.	Depends on distance to forest lands. Scheduling affected by climate and maturity of trees.	Depends on distance to disturbed lands. Scheduling affected by climate and availability of new sites.	Usually least transport of all options. Scheduling affected by climate.
Sludge Application	Usually routine when appropriate application vehicles are used. May be limited by cropping pattern.	Can be difficult due to limited access roads and uneven terrain. May involve specially designed application equipment.	Usually routine, but may may be complicated by irregular terrain at many disturbed sites.	Usually routine.

TABLE 2-1 (continued)

Characteristics	Agricultural Utilization	Forest Land Utilization	Land Reclamation Utilization	Dedicated Disposal Site
Sludge nutrients beneficially recycled	Yes, reduces or eliminates commercial fertilizer use.	Yes, reduces or eliminates commercial fertilizer use.	Yes, reduces or eliminates commercial fertilizer use.	Sometimes, but not primary objective.
Potential benefits to existing soil condition	Depends on existing soil characteristics	Depends on existing soil conditions.	Yes, allows soil to support vegetation and retards erosion.	Usually soil is restricted for future agricultural use.
Dramatic improvement in vegetative growth response	May improve production, or just replace commercial fertilizers.	Yes, demonstration projects show great impact.	Yes, demonstration projects show great impact.	Not applicable.
Potential harmful impact (phytotoxicity) on vegetation grown	Avoided with proper selection of sludge application rates and accumulative total sludge applied.	Avoided with proper selection of sludge application rates and accumulative total sludge applied.	Not usually a concern because of typical one-time application.	Not applicable. Crops not a primary objective.
Potential degradation of surface waters or ground waters	Avoided with proper site(s) selection and design, and control of application rates.	Avoided with proper site(s) selection and design, and control of application rates.	Often the disturbed land site is already a source of water degradation. Proper sludge application and management may alleviate existing problems.	Yes, can be a major danger unless site is carefully selected and designed.
Potential public health and/or nuisance impact	Can be avoided with proper design and operation.	Can be avoided by proper operation and controlling public access.	Not usually a problem if public access is controlled.	Yes, can be avoided with proper design and operation and controlling public access.
Monitoring required of water, soil, crops, etc.	Usually not extensive.	Usually not extensive.	Usually not extensive, but may be complicated by irregular soil distribution in many disturbed sites.	Usually substantial.
Existing projects using this option (1982)	Hundreds of large and small full-scale projects.	A few demonstration projects.	A few full-scale and demonstration projects.	A few full-scale and demonstration projects.
Existing regulations available on which to base process design (1982)	Extensive; most states have regulations or guidelines in place.	Limited; proposed projects handled on a case-by-case basis.	A few states have regulations, generally projects handled on a case-by-case basis.	Limited, proposed projects usually handled on a case-by-case basis.
Availability of technical literature pertaining to this option (1982)	Extensive.	Limited.	Limited.	Limited and not always easy to locate. Much is in the form of private engineering reports for specific projects.

the farmers and to minimize need for environmental monitoring. Application is at agronomic rates, usually on an annual basis.

- Chapter 7, Forest Land Application, can be limited by the N need of the trees, i.e., application at silvaculture use rates. Sludge is often applied only one time, or at multi-year intervals, e.g., every 5 years, to a specific area.
- Chapter 8, Application to Disturbed Land for Reclamation, is typically limited by the cumulative metals loadings. Usually there is only one application to a site. In some cases, nitrogen may be a factor to protect drinking water quality in aquifers.
- Chapter 9, Application to Dedicated Sludge Disposal Site, is primarily limited by site-specific soils and hydrogeologic conditions, climate, and vegetation (if grown). Usually there are many sludge applications per year to the same site area. Careful protection of ground water aquifers is a major feature of these systems.

A limitation to all of the options is that sludge may contain materials that are potentially harmful to surface waters, ground waters, and public health. To avoid these problems, the site selection, design, and management of land application systems require careful attention.

2.2 Agricultural Utilization

2.2.1 Purpose and Definition

Agricultural utilization of sludge is practiced in nearly every state, and is especially common in New Jersey, Pennsylvania, Ohio, Illinois, Michigan, Missouri, Wisconsin, and Minnesota. Hundreds of communities, both large and small, have developed successful agricultural utilization programs. These programs benefit the municipality generating the sludge by providing an ongoing environmentally acceptable means of sludge disposal, and provide the participating farmer with a substitute or supplement for conventional fertilizers.

The agricultural utilization option assumes that the sludge is applied at "agronomic rates," defined as the annual rate at which the N and/or P supplied by the sludge and available to the crop does not exceed the annual N and/or P requirement of the crop. The amount of plant available N or P applied to the site is based on that required by the crop. In the case of N, the farmer would have applied this quantity of available N as commercial fertilizer. By limiting N loadings to fertilizer recommendations, the impact on ground water should then be no different from normal agricultural operations. Chapter 6 of this manual provides details of agronomic rate calculations, limitations, etc.

2.2.2 Advantages of Agricultural Utilization

Sludge contains several plant macronutrients, principally N and P, and in most cases, significant amounts of micronutrients such as boron (B), manganese (Mn), copper (Cu), molybdenum (Mo), and zinc (Zn). The exact ratio of these nutrients will not be that of a well-balanced formulated fertilizer; nevertheless, most agronomic crops respond favorably to the nutrients in sludge.

Sludge may also be a valuable soil conditioner if added at rates greater than agronomic rates. The addition of sludge to a fine-textured clay soil can make the soil looser and more friable, and increase the amount of pore space available for root growth and the entry of water and air into the soil. In coarse-textured sandy soils, sludge can increase the water-holding capacity of the soil, and provide chemical sites for nutrient exchange and adsorption.

The municipality(ies) generating the sludge may benefit, because, in many cases, agricultural utilization is less expensive than alternative methods of sludge management/disposal. The general public may benefit from cost savings resulting to the municipality(ies) and the farmers using the sludge. The recycling of nutrients is attractive to citizens concerned with the environment, and resource conservation.

A major advantage of agricultural utilization is that usually the municipality does not have to purchase land. Further, the land utilized for sludge application is kept in production. Its value for future uses is not impaired, and it remains on the tax roles.

A final advantage is that agricultural utilization usually takes place in a relatively rural setting. The sludge application operations are similar to conventional farming operations, and are not likely to create public complaints if properly managed.

2.2.3 Limitations and Potential Disadvantages of Agricultural Utilization

Sludge may contain constituents which are potentially harmful to the crops themselves (phytotoxicity), or to animals and humans who consume the crops. To avoid this problem, the quantity of sludge which may be applied per unit of land area, both on an annual and cumulative basis, should be controlled in accordance with regulatory limits or guidelines, and good management practices, as detailed in Chapter 6. Cadmium (Cd), a sludge constituent of widespread concern, has been extensively studied. Its application to cropland is regulated (see Chapters 4 and 6). In general, municipalities which collect and treat substantial amounts of industrial wastes from manufacturing industries may generate sludge which contains relatively high levels of potentially harmful constituents. (See Appendix A for typical sludge characteristics.) These municipalities should carefully review the limitations placed on sludge application to cropland (Section 6.4 of Chapter 6) before initiating an agricultural utilization program.

Sludge application rates for agricultural utilization (dry unit weight of sludge applied per unit of land area) are usually relatively low. Thus, large land areas may be needed, requiring the cooperation of many individual land owners. In addition, the scheduling of sludge transport and application scheduling for agricultural planting, harvesting, etc., plus adverse climatic conditions, will require careful management. If the farms accepting sludge are numerous and widespread, an expensive and complicated sludge distribution system may be required.

2.3 Application to Forest Lands

2.3.1 Purpose and Definition

Except for certain areas in the Great Plains and the southwest, forested lands are abundant and well distributed throughout most of the United States. Many major municipalities are located in close proximity to forests; in fact, it is estimated that close to one-third of the land within the standard metropolitan areas is forested. Furthermore, approximately two-thirds of all forest land in the United States is commercial timberland (12). Thus, the application of sludge to forest soils has the potential to be a major sludge utilization/disposal option.

Unlike agricultural utilization, sludge application to forest lands is not a common practice. In 1982, demonstration projects were ongoing in several regions of the country (see Chapter 7). These demonstration projects strongly indicate that forest application of sludge is a feasible option. However, the technical data base needed to design such projects is incomplete. Users of this manual who are considering sludge application to forest land are advised to contact the cities, agencies, etc., listed in Chapter 7 to obtain updated information.

Three categories of forest lands may be available for sludge disposal:

- Recently cleared land prior to planting.
- Newly established plantations (about 3 to 10 years old).
- Established forests.

The availability of sites and the relative advantages and disadvantages of each approach will determine which option or combination of options is best for a given situation.

2.3.2 Advantages of Forest Land Utilization

Sludge contains nutrients and essential micronutrients often lacking in forest soils. Demonstration projects have shown greatly accelerated tree growth resulting from sludge application to both newly established plantations and established forests. In addition, sludge contains organic matter which can improve the condition of forest soils by increasing the permeability of fine-textured clay soil, or by increasing the water-holding capacity of sandy soils.

Since forests are not a food chain crop, there are fewer public health-related concerns with the plant uptake of sludge constituents than with agricultural use of sludge. In addition, research indicates that some tree species are very tolerant to constituents in sludge (e.g., metals) which may be harmful (phytotoxic) to certain agricultural crops.

Municipality(ies) located near forest lands may benefit, because forest land utilization may be less expensive than alternate methods of sludge management/disposal. The general public may benefit from cost savings realized by the municipality(ies) and the commercial growers using the sludge. The recycling of nutrients is attractive to environmentally concerned citizens. For example, Seattle, Washington, is developing a long-term program to apply sludge to forest lands in a systematic, well-managed program. For Seattle, the proposed program appears to be the least expensive method of sludge utilization/disposal, and has strong public support. Since forests are perennial, the scheduling of sludge applications is not as complex as it may be for agricultural utilization programs when planting and harvesting cycles must be considered. In some cases, the sludge application to forest soils may be a one-time application, or applications may be scheduled at 3- to 5-year intervals.

A final advantage of forest land utilization is that the municipality usually does not have to pay for acquiring land.

2.3.3 Limitations and Potential Disadvantages of Forest Land Utilization

Since sludge application to forest lands is not widely practiced, the designer of a proposed new program will probably have few regulations or nearby existing similar programs to use for guidance. This information gap may necessitate substantial preliminary effort with regulatory agencies, forest land owners, and the general public to obtain approval for a proposed new program.

It may be difficult to control public access to sludge-amended forest lands. The public is accustomed to free access to forested areas for recreational purposes, and may tend to ignore posted signs, fences, etc. Control of public access is needed for up to 12 months after liquid sludge is sprayed on forested areas.

Access into some forest lands may also be difficult for conventional sludge application equipment. Terrain may be uneven and obstructed. Access roads may have to be built and/or specialized sludge application equipment used, or developed.

2.4 Application for Reclamation of Disturbed and Marginal Lands

2.4.1 Purpose and Definition

The surface mining of coal, exploration for minerals, generation of mine spoils from underground mines, and tailings from mining operations have created over 1.5 million ha (3.7 million ac) of drastically disturbed land. The properties of these drastically disturbed and marginal lands vary considerably from site to site. Their inability to support vegetation is the result of several factors:

- Lack of nutrients - The soils have low N, P, K, and/or micronutrient levels.
- Physical properties - Stony or sandy materials have poor water-holding capacity and low cation exchange capacity (CEC). Clayey soils have poor infiltration, permeability, and drainage.
- Chemical properties - The pH of mine soils, tailings, and some drastically disturbed soils range from very acidic to alkaline. Potentially phytotoxic levels of Cu, Zn, Fe, and salts may be present.
- Organic matter - Little, if any, organic matter is present.
- Biological properties - Soil biological activity is generally reduced.
- Topography - Many of these lands are characterized by steep slopes which are subject to excessive erosion.

Historically, reclamation of these lands is accomplished by grading the surface to slopes that minimize erosion and facilitate revegetation. In some cases, topsoil is added. Soil amendments such as lime and fertilizer are added, and grass, legumes, and/or trees are planted. Although these methods are sometimes successful, numerous failures have occurred, primarily because of the very poor physical, chemical, or biological properties of these disturbed lands.

There have been a number of successful land reclamation projects involving the use of sludge or sludge compost. Most have been conducted on strip-mined land or mine tailings in the Eastern coal states of Pennsylvania, Illinois, Virginia, West Virginia, and Alabama. Projects in Venango, Somerset, Westmoreland, and Lackawanna Counties, Pennsylvania, have involved reclamation of bituminous and anthracite strip-mine soil banks with sludge or sludge compost. The soils were backfilled, recontoured without topsoil, and treated with lime to raise the pH to 7. Sludge was applied at rates commensurate with the physical/chemical characteristics of the mine soils and state guidelines.

Similar reclamation projects have been conducted at Fort Martin, West Virginia; Contrary Creek, Virginia (abandoned pyrite mine tailings); Fulton County, Illinois (Prairie project); and the Shawnee National Forest (PALZO Tract), Illinois. No serious ground water degradation problems associated with sludge application has been documented at any of these sites.

Typically, sludge is applied only once to land reclamation project sites. Therefore, an ongoing program of sludge application to disturbed lands requires that a planned sequence of additional sites be available for the life of the program. This objective may be achieved through arrangements with land owners and mining firms active in the area, or through the planned sequential rehabilitation of existing disturbed land areas. In some cases, reclaimed areas may be used for agriculture production using agronomic rates of sludge application.

2.4.2 Advantages of Utilizing Disturbed and Marginal Lands

This option may be extremely attractive in areas where disturbed and marginal lands exist because of the dual benefit to the municipality in disposing of its sludge, and to the environment through reclamation of unsightly, largely useless land areas.

Sludges have several characteristics which make them suitable for reclaiming and improving disturbed lands and marginal soils. One of the most important is the sludge organic matter which (1) improves soil physical properties by improving granulation, reducing plasticity and cohesion, and increasing water-holding capacity; (2) increases the soil cation exchange capacity; (3) supplies plant nutrients; and (4) increases and buffers soil pH.

The natural buffering capacity and pH of most sludges will improve the acidic or moderately alkaline conditions found in many mine soils. Immobilization of heavy metals is pH-dependent, so sludge application reduces the potential for acidic, metal-laden runoff and/or leachates. Sludge is also desirable, because the nutrients contained therein may substantially reduce commercial fertilizer needs. Furthermore, sludge helps to increase the number and activity of soil microorganisms.

The amount of sludge applied in a single sludge application can often be greater for land reclamation than for agricultural utilization, provided that the quantities applied do not pose a serious risk of future plant phytotoxicity or unacceptable nitrate leaching into a potable ground water aquifer, and regulatory agency approval is granted. In some cases, serious degradation of surface and ground water may exist at the proposed site, and a relatively heavy sludge addition with subsequent revegetation can be justified as improving an already bad situation. The municipality usually does not have to purchase land for reclamation projects. In addition, disturbed or marginal lands are usually located in rural, relatively remote areas.

2.4.3 Limitations and Potential Disadvantages of Disturbed or Marginal Land Reclamation

Plant species selected for use in revegetation should be carefully selected for their tolerance to sludge constituents and their suitability to local soil and climate conditions. If crops intended for animal feed or human consumption are planted, the same limitations (e.g., Cd) exist as apply to agricultural utilization of sludge.

Disturbed lands, especially old abandoned mining sites, often have irregular, excessively eroded terrain. Extensive grading and other site preparation steps may be necessary to prepare the site for sludge application. Similarly, disturbed lands often have irregular patterns of soil characteristics. This may cause difficulties in sludge application, revegetation, and future site monitoring.

Only a few states have developed specific regulations (e.g., Pennsylvania, Illinois) or guidelines (e.g., New York) for sludge application to disturbed or marginal lands. Therefore, many proposed new projects may be faced with an extensive preliminary pioneering effort to obtain regulatory agency approvals.

2.5 Dedicated Land Disposal

2.5.1 Purpose and Definition

The definition of a dedicated land disposal (DLD) site is less clear than the other options described in the preceding sections. Generally, a DLD project has the following characteristics:

- The primary purpose is long-term sludge application, i.e., it is a dedicated disposal site for landspreading of sludge. Any additional site activities or benefits, such as the production of agricultural crops or improvement of soil characteristics, are secondary to the sludge disposal activity.
- Normally, sludge application rates are substantially higher than for other options, e.g., agriculture, forest, etc. Obviously, higher application rates reduce the area of land required.
- Usually, the municipality(ies) owns or has a long-term lease on the land, which allows the agency substantial discretion in use of the land for sludge disposal purposes.
- Usually, the site needs to be more carefully designed, managed, and monitored than sites where sludge is applied at agronomic rates as a fertilizer amendment to cropland, forest land, etc.
- Site design and operations are focused upon containing any environmentally detrimental sludge constituents within the dedicated disposal site. Surface runoff, ground water leachate, and harvested crops (if any) are carefully controlled. Strict controls are virtually always required, and permitting procedures often involve many agencies.

A special case included within the DLD site definition is when sludge is applied to cropland at higher than agronomic rates (see Section 2.2.1 for definition of agronomic rates). Regulations generally require that projects involving sludge utilization at greater than agronomic rates implement an extensive facility management plan to prevent adverse environmental impacts, and impose restrictions on the end use of the crops grown. In 1981, there were at least 20 operational DLD sites in the United States.

2.5.2 Advantages of Dedicated Land Disposal

Generally, sludge is applied to DLD sites at high annual application rates for many years; smaller land areas are thus required than for the other land application options discussed in previous sections. Since less land area is required, the municipality may be able to find a suitable site close to the POTW(s), thereby reducing sludge transport costs. Pipeline transport of sludge in lieu of vehicle transport is often feasible.

Sludge quality in terms of potential contaminant concentrations is usually less of a constraint with this option. Therefore, sludges which are not of suitable quality for the other options may be acceptable for DLD.

The municipality normally owns or controls the DLD site(s) under a long-term lease. This eliminates the need for contractual arrangements with privately owned farms, tree growers, mining operations, etc., usually required by the alternative options. In addition, direct control of the land allows much greater control of sludge application scheduling, rates, and procedures. On-site construction (e.g., grading, drainage, storage, fencing, roads, etc.) can be implemented to optimize future operations without concern for its impact on a private owner. The municipality has the security of an assured long-term facility dedicated to sludge disposal as its primary objective.

2.5.3 Limitations and Potential Disadvantages of Dedicated Land Disposal

Sludge application rates for DLD sites are usually much higher than those required for vegetation growth and/or soil enhancement. Therefore, sludge constituents accumulate at a higher rate on the site. This requires:

- Generally, that the land must be purchased or leased, resulting in land costs to the municipality and probable removal of the land from the tax rolls. Sometimes land condemnation proceedings may be necessary to acquire an appropriate site. Objections by neighboring property owners are also likely.
- Sites be carefully designed, constructed, and managed to retain on site the excess sludge constituents which could degrade the surrounding environment. Surface water runoff and ground water leachate must usually be controlled, often by construction of relatively expensive collection systems, retention structures, etc.

- Buildup of metals, salts, etc., in the soil may make the DLD site soil unsuitable for future use in agricultural production, forestry, etc., because of phytotoxicity. Deed restrictions prohibiting future agriculture use of the site may be required.

- Regulatory agency requirements for monitoring of potential ground water and surface water contamination are usually more extensive than required for the other land application options.

Because large quantities of sludge are continually applied at a DLD site, the potential is higher for nuisances such as odor, noise, dust, and spills. A DLD site must generally be carefully located, managed, and operated to avoid complaints by the public.

Permitting procedures may be complex and time-consuming, requiring extensive site investigations, design approvals, reporting to regulatory agencies, and closure/post-closure plans.

2.6 Other Sludge Utilization Options

There are a number of sludge land application practices which have been studied, but to date have not been used on a large scale. Several of these options possess sludge utilization/disposal potential.

2.6.1 Turf Farms

The nutrients and soil amendment properties of sludge make it potentially valuable and effective for use in sod production. One advantage is that the organic N in sludge is released and becomes available for plant growth over a relatively long period of time. This greatly reduces the amount and/or frequency of inorganic N application. Another advantage is that turfgrass is a non-food chain crop; consequently, heavy metal uptake is a lesser concern. In addition, turfgrasses are generally more tolerant of soil heavy metal and salt concentrations than many other crops.

The use of sludge in commercial sod production has great potential (29). Dried or composted sludges provide an ideal growth medium for most turfgrasses. Liquid sludges possess many of the same benefits, but are less convenient to handle.

Seedling establishment is more rapid in composted sludge/soil mixtures than with conventional sod seeding practices. Sod grown with sludge-compost/soil mixtures weighs about 30 to 40 percent less than normal soil sod (29, 31, 32). With surface application of composted sludge, little or no herbicides are generally required. Liquid sludges often contain viable seeds of undesirable plants, e.g., tomatoes, which will require weed control.

2.6.2 Parks and Recreational Areas

There have been two basic approaches to sludge use in parks and recreational areas: (1) land reclamation followed by park establishment, and (2) use of sludge as a substitute for conventional fertilizers in the maintenance of established parkland vegetation. Sludge can supply a portion of the nutrients required to maintain lawns, flower gardens, shrubs and trees, golf courses, recreational areas, etc. (19, 31, 32, 33, 34).

Although sludge use can be beneficial for park maintenance, there are a number of disadvantages associated with its use:

- Liquid sludge application may be odorous, and presents potential public health problems from sludge-borne pathogens.
- The use of sludge on close-cut, highly maintained turf, such as golf courses, may be aesthetically objectionable, because of a black residue left on the surface of the sod.
- Public relations problems dealing with popular misconceptions and objections to sludge use in public places may develop.

All of the above-listed objections are significantly minimized if heat-dried or composted sludge is used.

2.6.3 Highway, Airport, and Construction Site Landscaping

The construction of highways, airports, major buildings, shopping malls, etc., frequently creates large areas of marginal, eroded, or generally poor-quality soils. Landscaping is required to improve aesthetics and control erosion. Sludge is an excellent soil conditioner and nutrient source. All forms of sludge (i.e., liquid, dewatered, dried, or composted) can be mixed with these soils before planting to provide a soil environment suitable for vegetative growth. Sludges can also be used in lieu of conventional fertilizers to provide many of the nutrients needed to maintain the established vegetation (19, 31, 33, 34).

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CHAPTER 3

PUBLIC PARTICIPATION

3.1 Introduction

A community's willingness to cooperate with a sludge-to-land application project varies with its perceptions of the project's potential benefits and costs. For a land application project to gain public acceptance, the community must determine that the benefits are greater than any possible or perceived burdens (e.g., odors, noise, truck traffic, etc.).

A major public acceptance barrier which has surfaced in many documented case studies is the widely held perception that sludge is malodorous, highly contaminated, and otherwise repulsive. Experience has shown that such public apprehension can be partially allayed through public education campaigns, adequate planning, and, most importantly, small demonstration or pilot programs (1).

Planning for public participation in a land application project involves careful and early evaluation of who should be involved, to what degree, and for what purpose. Clearly defined objectives will simplify decisions, and will help to keep the program from becoming too diffused and ineffective. The following discussion presents a summary of the major considerations necessary to implement a successful program. A more detailed discussion of public participation programs is presented in Reference (5). Potential mitigation of public acceptance problems is discussed in Reference (1).

3.1.1 Objectives

The major objectives of a public participation program include:

1. Providing the community with sufficient technical information to clearly define the advantages and disadvantages of the proposed project. Technical information should be presented in an easily understandable manner to ensure communication between the public, engineer, planner, consultant, regulatory, and other officials.
2. Convincing landowners who are potential participants that it is in their best interest to participate in the project.
3. Correcting any misinformation that exists within the community.
4. Keeping the community informed of plans as they develop.
5. Soliciting suggestions and support from both the proposed project participants and their neighbors.

Most programs will aim at the first of these objectives, and many will pursue the second and third. The fourth and fifth objectives, taken in conjunction with the first three, suggest a willingness to involve the community, to listen to and use their suggestions, and to make the public part of the planning team. The perspective of the engineering/planning team should be one of cooperation rather than confrontation.

3.1.2 Elements of Successful Public Involvement Programs

One should begin with the existing sludge management system and the need to change it. Citizens should be told how the wastewater treatment process functions, and what it means to the community. Sludge should be defined, along with an explanation of where it originates and its composition and volume before and after treatment. Sludge management should be related to the public's demand for clean water (2).

Agency and other project personnel should be trained in public contact. Personnel should be well prepared to translate technical concepts into simple, clear terms; they should also be prepared to deal with hostile audiences. The attitudes displayed by project staff members do much to create credibility or engender hostility.

The public's real concerns should be identified. Often, publicly expressed concerns mask the real reasons for opposition. For example, property owners adjacent to a sludge application site may sound alarms about ground water pollution when their major concern is actually property value depreciation (2).

3.1.3 Participants

It is essential that a group of knowledgeable and enthusiastic resource people participate in a land application program. This group should include the following participants (9):

- University staff and federal and state experts who can provide valuable research and technical information on land application of sludge, and whose credibility usually reduces concern and misunderstanding among concerned individuals or groups.
- POTW managers and city officials who can provide background information on municipal sludge problems.
- Local or state cooperative extension staff who can assist in the organizational aspects of community meetings.
- Various agency personnel, including health officials, soil conservation staff, state environmental protection staff, etc., who will express their concerns and policies as they influence the design of a proposed project.

Other local organizations/persons who should be involved in the development of a land application project can include:

- Recipients (e.g., farmers, tree growers, mine landowners, etc.) who will use the sludge, and their neighbors.
- Consulting engineers, and waste management firms.
- Farming, forestry, mining, and other local organizations, e.g., Farm Bureau, Soil and Water Conservation Districts.
- Crop processors and produce users (via business, trade, and consumer organizations).
- News/communications media.

The actual project participants, whether on an active or an informational basis, will vary with the choice of land application option. In each case, a broad spectrum of participants should be considered early in the project. The number of participants can be narrowed later, as necessary.

3.1.4 Methods

A number of methods are available for communicating the need for and feasibility of a proposed project, and the technical information needed to understand the project and to gain the support of individuals within the community. Not all will be needed in all cases.

The information transfer process must address all of the advantages and disadvantages of sludge use on land. Any potential problem which is not publicly addressed at the outset of a project will likely be brought to the attention of the media, resulting in the possible reduction of public support and the loss of the project leadership's credibility.

3.1.4.1 Formal Methods

- Public hearings or meetings may be required and/or desirable for most types of projects.
- Workshops can bring together professional planners and public officials with landowners and others who will be directly involved. Specialized workshops, such as one involving landowners who have expressed tentative interest and others who have already participated in a similar project, may be especially beneficial.
- An Advisory Committee, composed of representatives from local government, consumer/business organizations, environmental protection organizations, processors, and planners, can be useful for maintaining contact with both the general public

and interested organizations. Such a committee should be formed early in the planning stages. Its meetings should be scheduled such that there is time for its views to be heard and carefully considered before final decisions are made.

- A mailing list is helpful for disseminating information as the project proceeds. All interested persons and organizations should be included. The list should be kept current, and a continuing effort should be made to keep all who are interested informed.

- Advertising and public relations techniques, such as press releases, pamphlets, and brochures; and radio, television, or newspaper feature stories and advertisements.

3.1.4.2 Informal Methods

- Open meetings, less structured than public hearings or workshops, can be held in conjunction with meetings of an Advisory Committee or other interested organizations, such as the Town Council, etc. These meetings provide a more relaxed forum for the exchange of information and views. They also offer the professional planner/engineer with an ideal opportunity to listen to the community and to become aware of misinformation which may exist concerning potential problems associated with land application of sludge.

- Personal contacts or interviews with potential participants may be the most effective means of soliciting participation. Contacts can be made in cooperation with local planners or county extension agents who are already familiar with the community.

- Demonstrations and field days can create opportunities for the public to see sludge utilized as a resource. Allowing people to see, feel, and smell treated, stabilized sludge can often be good public relations.

- Traveling displays can be set up to inform the public in a visually interesting manner; these displays can be moved to such locations as public libraries, shopping centers, etc. (2).

3.1.5 Timing

A public participation program should begin very early in the development of a proposed project, and should continue throughout the project. All persons concerned should have the opportunity to express their views before any decisions affecting the general public are made. They should then be kept informed and involved throughout the course of the project.

3.2 Public Participation Considerations Specific to Agricultural Utilization

Project implementation requires acceptance and approval by local officials, farmers, landowners, and other affected parties. Public resistance to agricultural utilization of sludge can stem from fear that the sludge may contain concentrations of organic or inorganic substances that could be toxic to plants, or accumulate in animals or humans consuming crops grown on sludge-treated lands.

The most critical aspect of the program is securing the involvement of farmers who will utilize the sludge. How this involvement is to be secured during the planning process depends on the individual communities involved; their past experience with sludge application systems; overall public acceptance of the concept; and the extent to which related or tangential environmental concerns are voiced in the community.

Generally, a low-key approach is most effective. The various approaches can consist of one or more of the following steps:

- Check with the POTW to see if any local farmers have requested sludge in the past.
- Have the local Soil Conservation Service or agricultural extension service agent poll various individuals in the area for expressions of interest.
- Describe the project in the local newspaper, asking interested parties to contact the extension agent.
- Personally visit the identified parties and solicit their participation. A telephone contact will elicit little support unless followed by a personal visit.

The use of demonstration plots is very effective in promoting the utilization of sewage sludge by farmers. If farmers can compare crops grown on sludge-treated soil with these grown with conventional fertilizer, their willingness to use sludge will increase markedly (3). The following questions regarding sludge utilization need to be discussed with landowners:

- How long is the landowner willing to participate (e.g., a trial period of 1 or more years; open-ended participation; until one or both parties decide to quit; for a prescribed period of time)?
- What crops are traditionally planted, and what is the usual crop rotation?
- If the sludge characteristics were such that a different crop is desirable, would the landowner be willing to plant that crop?

- Which fields would be included in the sludge application program?

- Under what conditions would the landowner accept the sludge, what time of the year, and in what quantities?

- Is the landowner willing to pay a nominal fee for the sludge, or accept it free of charge, or must the municipality pay the landowner for accepting sludge?

- Is the landowner willing to engage in special procedures, e.g., maintaining soil pH at 6.5 or greater?

The public relations program should emphasize both the benefits and the potential problems of applying sludge on cropland.

3.3 Public Participation Considerations Specific to Forest Utilization

No operational full-scale forest application programs in the United States were identified at the time this manual was prepared in 1982, although there were a few such programs planned for implementation in the near future. Thus, proponents of a new program will have obvious handicaps in gaining acceptance of new, relatively unproven sludge application techniques. On the positive side, proponents can emphasize the successful forest application demonstration projects listed in Table 7-1, and the basic similarities between forest application and agricultural application.

To help achieve acceptance, a forest application program should satisfactorily address the following questions:

- How will public access be controlled in the application area for an appropriate period (normally 12 to 18 months) after sludge application? Forested areas are often used for various recreational activities (e.g., picnicking, hiking, gathering of forest products, etc.). Even privately owned land is often viewed by the public as accessible for these purposes. The owner of the land, private or public, will have to agree to a method for controlling public access (e.g., fence, chain with signs, etc.). The public, through its representatives, must agree to restrictions if the land is publicly owned.

- Will public water supplies and recreational water resources be adequately protected against contamination? This concern should be covered by proper siting, system design, and monitoring. Public health authorities and regulatory agencies must be satisfied and involved in the public participation program. Careful consideration must be given to municipal watersheds and/or drinking water recharge areas to avoid contamination.

- Will the applied sludge cause adverse effects to the existing or future trees in the application area? Based on the available data from research and demonstration projects, many tree species, with few exceptions, respond positively to sludge application, provided the sludge is not abnormally high in detrimental constituents, and proper management practices are followed.

- Unlike most agricultural applications, there is much less concern about possible food chain transmission of contaminants to man. The consumption of wild animals by hunters and their families will occur, but there is little potential for contamination of meat from such animals through contact with a properly managed sludge application area.

3.4 Public Participation Considerations Specific to Disturbed Lands

Prior to the initiation of any reclamation project using sludge, it will likely be necessary to educate the public to gain public acceptability. The task may be difficult with lands disturbed by mining, because local opposition to mining activity already exists in many cases. This is particularly true if the mining activity has already created some adverse environmental problems, such as reduced local ground water quality, acid mine drainage, or serious soil erosion and sedimentation of local streams.

Citizens, regulatory agencies, and affected private business entities need to participate in the planning process from the beginning. The most effective results are usually achieved when industry, citizens, planners, elected officials, and state and federal agencies share their experience, knowledge, and goals, and jointly create a plan acceptable to all.

Participation of local advisory groups is helpful. This procedure was used successfully in developing the Pennsylvania program for using sludge for reclamation of mined land. The Pennsylvania advisory group was composed of farmers, elected officials, representatives from the Soil Conservation District, Game Commission, Bureau of Forestry, the County Extension Agent, and Community Resources Agents. This group met quarterly with project personnel, and independently monitored several of the pilot demonstration sludge projects over a 2-year period. The results of their independent monitoring study, which included analyses of sludge delivered to several sites, vegetation, soils, and water, convinced them that the concept was technically sound and environmentally safe. All demonstrations were highly successful and paved the way for public acceptance of full-scale operations which are now under way in Pennsylvania.

Obviously, important participants are the owners of the disturbed land. For a continuing program, it is usually necessary to make contractual arrangements with the owner(s) to ensure that the areas of disturbed land needed for sludge application will be available during future years of project operation.

3.5 Public Participation Considerations Specific to Dedicated Land Disposal

Virtually all proposed dedicated land disposal (DLD) projects will undergo an extensive public participation process. The project proponents should show that the DLD option is the most suitable project alternative in terms of economics, technical feasibility, and environmental impact.

Since DLD sites are normally intended for long-term use, adjacent property owners will be particularly concerned about potential odors, pathogens, vectors, noise, dust, traffic, aesthetics, and other factors affecting their quality of life and the resale value of their property. Proper design and operational management will help to eliminate or minimize these concerns. A large buffer area around the sludge application area is usually desirable.

3.6 References

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4. Sagik, B. P., B. E. Moore, and C. A. Sorber. Public Health Aspects Related to the Land Application of Municipal Sewage Effluents and Sludges. In: Utilization of Municipal Sewage Effluent and Sludge on Forest and Disturbed Land. W. E. Sopper, and S. M. Kerr, eds. Pennsylvania State University Press, 1979. pp. 241-263.
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CHAPTER 4

TECHNICAL ASSESSMENT AND PRELIMINARY PLANNING

4.1 General

The process of planning a sludge land application project begins with the collection and assessment of basic data on sludge characteristics. The sludge characteristics in conjunction with estimated application rates can then be compared to applicable federal, state, and local regulations for an initial assessment of sludge suitability for any of the options discussed in Chapter 2. The public's perception and acceptance of such a proposed project, as well as land availability, transportation modes, and climatic conditions must all be considered and evaluated to determine the feasibility of the proposed program.

Figure 4-1 presents a simplified flow diagram of the steps that should typically be followed during the early planning phases of a proposed project. This chapter addresses each of the sections shown on the flow diagram. Additional sources of information which may be needed throughout the various project planning and design phases are listed in Section 4.6 and 4.7.

4.2 Sludge Characterization

The characterization of sludge properties is a necessary first step in the design of a land application system. Estimates of current and future sludge quantities and quality are needed to determine land area requirements, site life, application rates, storage facilities, and cost.

Information about the physical characteristics of sludge is needed to select transportation and application methods. Chemical and biological characterization is required to determine the suitability of sludge for land application; the land application option(s) which may be appropriate for utilization or disposal; appropriate sludge application rates; and monitoring parameters. Consideration should be given to the feasibility of future changes in sludge processing and/or system design which would make the sludge more desirable for a land application option.

Appendix A provides detailed information about sludge characteristics; Appendix C summarizes sludge sampling and analytical procedures.

4.2.1 Physical Characteristics of Slud[illegible]

The physical characteristics of interest are solids content, expressed as percent solids. This affects the potential land application system design since:

- The higher the sludge solids content, the lower the volume of sludge that will have to be transported, stored, etc., because less water must be handled.

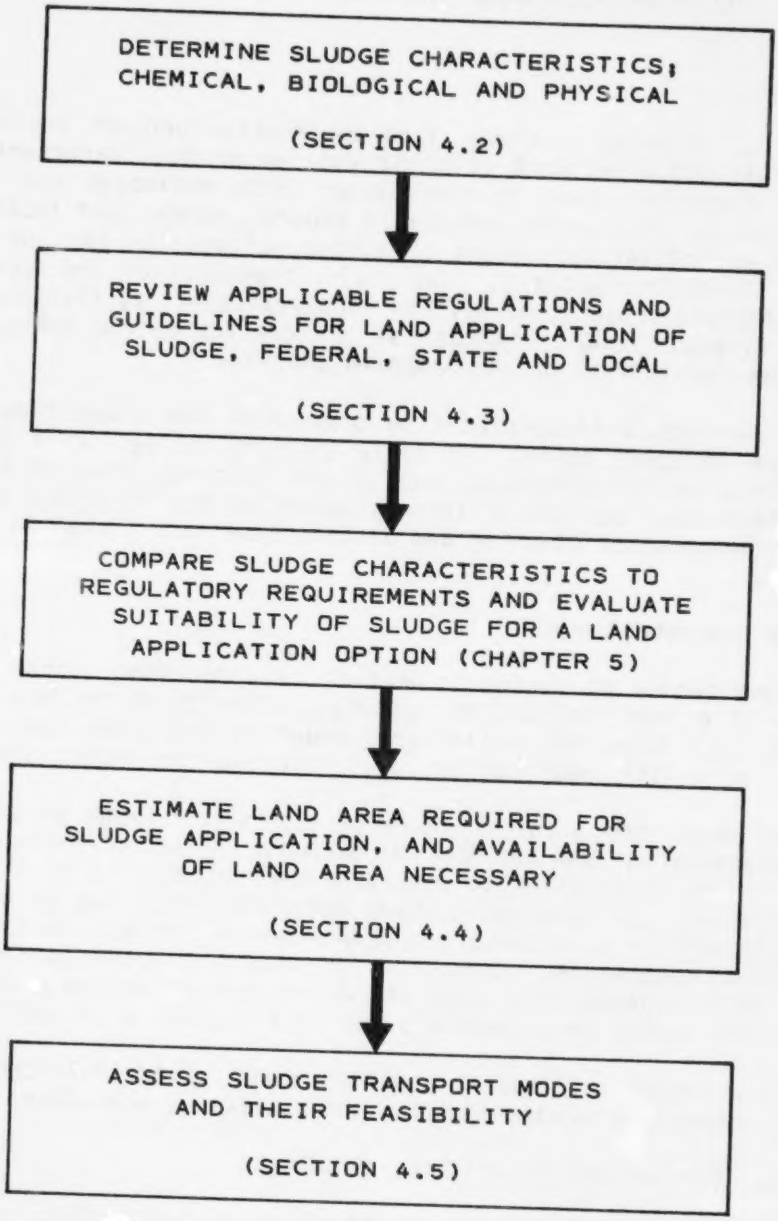
DETERMINE SLUDGE CHARACTERISTICS; CHEMICAL, BIOLOGICAL AND PHYSICAL
(SECTION 4.2)
REVIEW APPLICABLE REGULATIONS AND GUIDELINES FOR LAND APPLICATION OF SLUDGE, FEDERAL, STATE AND LOCAL
(SECTION 4.3)
COMPARE SLUDGE CHARACTERISTICS TO REGULATORY REQUIREMENTS AND EVALUATE SUITABILITY OF SLUDGE FOR A LAND APPLICATION OPTION (CHAPTER 5)
ESTIMATE LAND AREA REQUIRED FOR SLUDGE APPLICATION, AND AVAILABILITY OF LAND AREA NECESSARY
(SECTION 4.4)
ASSESS SLUDGE TRANSPORT MODES AND THEIR FEASIBILITY
(SECTION 4.5)

Figure 4-1. Simplified planning steps for a sludge land application option.

- The type of transport which can be utilized, e.g., truck type, feasibility of pipeline transport, etc. (see Chapter 10 for discussion).
- The method of sludge application and sludge application equipment needed, e.g., type of sludge application vehicle, need for incorporating the sludge into the soil, etc.
- The methods available to transfer and store sludge.

In general, it is less expensive to transport sludge which has a high solids content, i.e., dewatered sludge, than sludge with a low solids content, i.e., liquid sludge. This cost savings in sludge transport should be weighed against the cost of dewatering the sludge.

Typically, liquid sludge has a solids content of 2 to 10 percent solids, and dewatered sludge has a solids content of 20 to 40 percent solids, which includes the chemical additives. Dried or composted sludge typically has a solids content over 50 percent.

4.2.2 Chemical Characteristics of Sludge

The chemical composition of sludge varies greatly between sewage treatment plants (POTW's); also over time from a single POTW. Sludge composition depends principally on the characteristics of the raw sewage influent entering the POTW and the treatment processes used. It is generally true that the more industrialized a community is, the greater the possibility that heavy metals and persistent organics will be a potential problem for land application of sludge.

Routine sludge analyses for land application purposes should include total N, ammonia N, total P, K, Cu, Zn, Pb, Cd, and Ni. Other parameters which should be analyzed for, at least initially, to screen for abnormal sludge characteristics are Cr, B, As, Al, Co, Mo, sulfate, and PCB's. If the presence of relatively high concentrations of other priority pollutants is suspected, e.g., halogenated hydrocarbons, polynuclear aromatic compounds, etc., then these parameters should also be measured.

Table 4-1 presents concentrations of macronutients (N, P, K), heavy metals of primary concern, and PCB's in sludges from several sources (see Appendix A for more complete sludge composition data). The degree of variability of the individual components should be noted. The data shown in Table 4-1 and Appendix A are intended primarily for illustrative purposes. While the data are useful in preliminary planning, analysis of the actual sludge to be land-applied is necessary for design purposes. As discussed in Appendix A, many sludges show a wide variation in composition over time. Thus, it may be necessary to analyze a substantial number of sludge samples over a period of 2 to 6 months or longer to provide a reliable estimate of sludge composition.

TABLE 4-1
CHEMICAL COMPOSITION OF SEWAGE SLUDGES (2)(3)*

Component	Number of Samples	Range	Median	Mean
		(Percent)†		
Total N	191	<0.1-17.6	3.30	3.90
NH_4^+-N	103	5×10^{-4}-6.76	0.09	0.65
NO_3^--N	43	2×10^{-4}-0.49	0.01	0.05
P	189	<0.1-14.3	2.30	2.50
K	192	0.02-2.64	0.30	0.40
		(mg/kg†)		
Cu	205	84-10,400	850	1,210
Zn	208	101-27,800	1,740	2,790
Ni	165	2-3,520	82	320
Pb	189	13-19,700	500	1,360
Cd	189	3-3,410	16	110
PCB's	14	<0.01-23.1	3.90	5.15

* Data are from numerous types of sludges (anaerobic, activated sludge lagoon, etc.) in 15 states: Michigan, New Hampshire, New Jersey, Illinois, Minnesota, and Ohio (2); California, Colorado, Georgia, Florida, New York, Pennsylvania, Texas, and Washington (3); and Wisconsin (2)(3).

† Oven-dry solids basis.

The chemical characterization of the sludge affects the following design decisions:

- Whether the sludge can be cost-effectively applied to land.
- Which land application options are technically feasible.
- The quantity of sludge which can be applied per unit area of application site, both annually and cumulatively.
- The degree of regulatory control and system monitoring required.

4.2.3 Biological Characteristics

A detailed discussion of pathogens which may be present in sludge is provided in Appendix A. Generally, sludge intended for land application must be stabilized by chemical or biological processes. Stabilization greatly reduces odor potential and the number of pathogens in sludge, including bacteria, parasites, protozoa, and viruses (4). Nevertheless, most stabilized sewage sludge will still contain some pathogens, and safeguards are necessary to protect against possible contamination of operating personnel, the general public, and crops intended for human consumption. Usually, sludge biological characteristics are not directly analyzed, and the project designer relies on recommended operational controls and procedures to assure adequate pathogen reduction.

4.2.4 Data Sources

The wastewater treatment plant represents the most likely source of sludge data. If data have not been collected, a procedure for sampling and analyzing should be instituted to assure that representative data are obtained, as discussed in Section 11.4.2 and Appendix C.

4.3 Regulations and Guidelines

Land application of sludge may be regulated by federal, state, and local governments. Federal legislative authority for regulating land application of sludge is vested in the EPA by the Resource Conservation and Recovery Act of 1976 (RCRA) and the Clean Water Act of 1977 (CWA). Under this authority, the EPA promulgates and enforces regulations and guidelines which represent acceptable practices. The individual states have the responsibility of developing programs to implement these regulations and guidelines. In addition, some state and local governments have developed more stringent regulations (5). Some of the regulatory agencies which may have jurisdiction over municipal sludge land application programs are shown in Figure 4-2.

It is beyond the scope of this manual to detail all current regulations. It is, therefore, necessary for the system planner/designer to review current regulations with the cognizant regulatory and permitting agencies in the local area, state, and/or region where the proposed project will be located.

For preliminary guidance, a brief summary of some of the possible constraints applicable to a proposed land application project are presented below.

4.3.1 Floodplains

Land application sites generally should not be located where the land will be flooded, resulting in washout of the applied sludge from the application area. Appropriate construction of berms, dikes, channels,

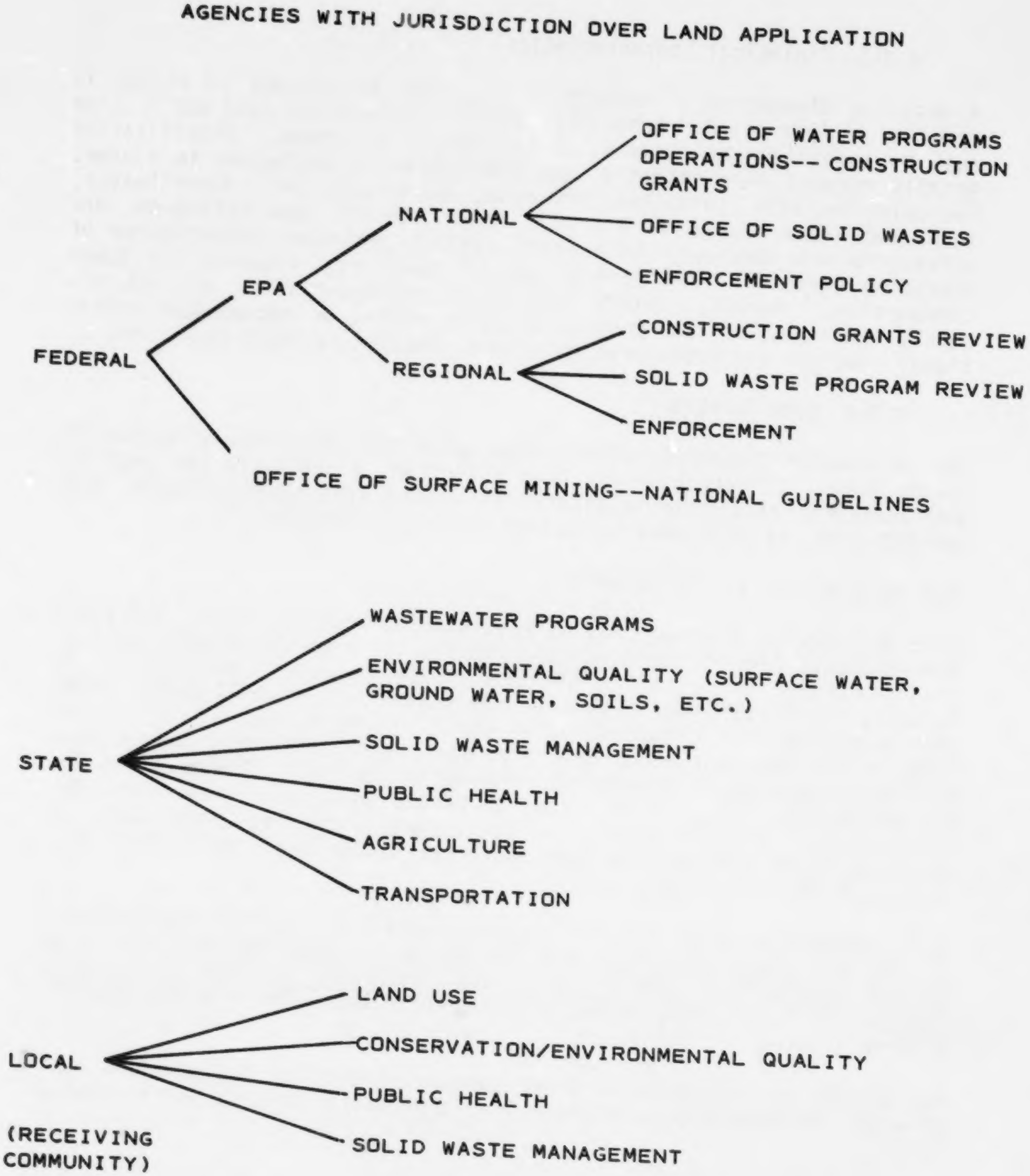
AGENCIES WITH JURISDICTION OVER LAND APPLICATION
FEDERAL
EPA
NATIONAL
OFFICE OF WATER PROGRAMS OPERATIONS-- CONSTRUCTION GRANTS
OFFICE OF SOLID WASTES
ENFORCEMENT POLICY
REGIONAL
CONSTRUCTION GRANTS REVIEW
SOLID WASTE PROGRAM REVIEW
ENFORCEMENT
OFFICE OF SURFACE MINING--NATIONAL GUIDELINES
STATE
WASTEWATER PROGRAMS
ENVIRONMENTAL QUALITY (SURFACE WATER, GROUND WATER, SOILS, ETC.)
SOLID WASTE MANAGEMENT
PUBLIC HEALTH
AGRICULTURE
TRANSPORTATION
LOCAL
(RECEIVING COMMUNITY)
LAND USE
CONSERVATION/ENVIRONMENTAL QUALITY
PUBLIC HEALTH
SOLID WASTE MANAGEMENT

Figure 4-2. Institutional framework (Ref. 5).

etc., can be implemented to protect against flooding, if necessary; however, increased costs are involved.

4.3.2 Surface Waters

The land application project should not cause unacceptable discharge of sludge pollutants into surface waters. In general, land application sites should be designed to prevent excessive surface runoff reaching rivers, streams, and lakes. If runoff is likely to be a problem, then appropriate controls should be employed to protect surface waters from either point source or non-point source pollution from a sludge land application site. Sludge soil incorporation practices can help to mitigate the potential for surface water runoff.

4.3.3 Ground Water

The land application project should not contaminate an existing or potential underground drinking water source (potable water aquifer) beyond the application site boundary. However, a state with a solid waste management plan approved by the EPA may establish an alternative boundary to be used in lieu of the application site boundary. A state may specify such a boundary only if it finds that such a change would not result in contamination of ground water which may be needed or used for human consumption. This finding is to be based on analysis and consideration of all of the following factors:

- Hydrogeological characteristics of the facility and surrounding land.
- Volume and physical and chemical characteristics of the leachate.
- Quantity, quality, and directions of ground water flow.
- Proximity and withdrawal rates of ground water users.
- Availability of alternative drinking water supplies.
- Existing quality of the ground water, including other sources of contamination and their cumulative impacts on the ground water.
- Public health, safety, and welfare considerations.

In essence, the project designer must show that either the leachate from the sludge disposal site will not contaminate the adjacent underlying ground water, or that it is of no significance since the ground water affected is not useful now or in the future (i.e., excluded aquifer). As explained in Chapters 6, 7, and 8, most states will accept application of sludge at agronomic rates as evidence that ground water contamination will not occur.

4.3.4 Odors and Air Quality

Generally, permit conditions will require that land application projects do not create nuisance odors beyond the application site boundary. How this is determined (measured) varies, depending on the regulatory agency and the proximity of the application site to public use areas. In addition, when liquid sludge is sprayed on the application site, it is usually a requirement that the public not be exposed to aerosols, created by the sludge application.

4.3.5 Public Access

Land application sites are generally required to limit exposure of the public to any potential health and safety hazards. The extent to which public access should be limited depends on (1) the degree to which the sludge has been treated to reduce pathogens (see Section 4.3.6), (2) the procedures used to apply and incorporate the sludge into the soil, (3) the remoteness of the sludge application site from public use areas, and (4) the ownership of the sludge application site area, whether private or public. In general, if there is an aspect of the operation that could expose the public to potential health and safety hazards, then fences or some other positive means of controlling public access is needed.

4.3.6 Sludge Treatment for Pathogen Reduction

Interim, final federal regulations (issued in September 1979) require that the sludge be treated by a "process to significantly reduce pathogens" prior to land application. The processes considered satisfactory to meet this requirement are the standard sludge stabilization processes, such as aerobic digestion, anaerobic digestion, air drying beds for at least 3 months, composting, and lime stabilization. Since these stabilization processes generally do not sterilize the sludge, the federal regulations require that public access be controlled for at least 12 months after sludge application, and that grazing by animals whose products are consumed by humans be prevented for at least 1 month after sludge application.

Crops for direct human consumption are a special case. If there is direct contact between the sludge and the edible portion of a crop grown for direct human consumption, federal regulations require that at least an 18-month period must elapse between the sludge application and growing of such crops, or that the sludge be subjected to further disinfection treatment prior to application. Disinfection treatment processes may include composting, heat drying, heat treatment, thermophilic aerobic digestion, pasteurization, and irradiation.

4.3.7 Sludge Application to Land Used for the Production of Food Chain Crops

The federal regulations cited above also include interim limits on Cd and PCB's, and set a minimum soil pH for soils used for sludge application which produce food chain crops. In 1982, additional guidance was issued by EPA/USDA/FDA for the use of sludge in the production of fruits and vegetables. (See Table 4-2 for a summary.) Chapter 6 discusses these limits in detail.

TABLE 4-2
SUMMARY OF JOINT EPA/FDA/USDA GUIDELINES FOR SLUDGE APPLICATION FOR FRUITS AND VEGETABLES PRODUCTION (7)

Annual and Cumulative Cd Rates

Annual rate should not exceed 0.5 kg/ha. Cumulative Cd loadings should not exceed 5, 10, or 20 kg/ha, depending on soil pH and CEC values of <5, 5 to 15, and >15 meq/100 g, respectively.

Soil pH

Soil pH (plow zone - top 6 in) should be 6.5 or greater at time of each sludge application.

PCB's

Sludges with PCB concentrations greater than 10 mg/kg should be incorporated into the soil.

Pathogen Reduction

Sludge should be treated by pathogen reduction process before soil application. Waiting period of 12 to 18 months before a crop is grown may be required, depending on prior sludge processing and disinfection.

Use of High-Quality Sludge

High-quality sludge should not contain more than 25 mg/kg Cd, 1,000 mg/kg Pb, and 10 mg/kg PCB (dry weight basis).

Cumulative Lead Application Rate

Cumulative Pb loading should not exceed 800 kg/ha.

Pathogenic Organisms

A minimum requirement is that crops to be eaten raw should not be planted in sludge-amended fields within 12 to 18 months after the last sludge application. Further assurance of safe and wholesome food products can be achieved by increasing the time interval to 36 months.

Physical Contamination and Filth

Sludge should be applied directly to soil and not directly to any human food crop. Crops grown for human consumption on sludge-amended fields should be processed with good food industry practices, especially for root crops and low-growing fresh fruits and vegetables.

Soil Monitoring

Soil monitoring should be performed on a regular basis, at least annually for pH. Every few years, soil tests should be run for Cd and Pb.

Choice of Crop Type

The growing of plants which do not accumulate heavy metals is encouraged.

4.3.8 Sludge Classified as Hazardous Wastes

In rare cases, a specific sludge may be so high in metal or organic contaminants that it would be classified as a hazardous waste under Subtitle C of RCRA. If the sludge being considered for land disposal or utilization is extraordinarily high in one or more of the priority pollutants (see Appendix A for typical sludge quality ranges), then the planner/designer should check the RCRA hazardous waste regulations. If a specific sludge is found to be a hazardous waste under RCRA definition, it must be disposed of at an acceptable hazardous waste facility.

The summary of regulations and guidelines provided in this manual is not intended to be complete; it also may not be current at the time that this manual is in general use. All current federal, state, and local regulations and guidelines should be reviewed during preliminary planning.

4.3.9 Possible Permits Required

The project designer should investigate pertinent regulations early in the planning for planned sludge land application projects. Depending on local procedures, permits may be required from both state and local regulatory agencies.

As in all cases where regulations are promulgated by more than one agency within the same jurisdiction, the most stringent rule must be followed in each case. It is therefore essential that the designer be aware of state regulations concerning the facility or practice, as well as any local regulations (county, municipal, or regional).

4.4 Estimate of Land Area Requirement

A precise estimate of the land area required for sludge application should be based on design calculations provided in Chapters 6, 7, 8, and 9 for the land application option(s) under consideration. However, for preliminary planning, a rough estimate of the land application area which might be necessary can be obtained from Table 4-3. (Note that the options may not necessarily involve repeated annual applications.)

As an example, assume that the project is intended to dispose 1,000 mt (1,100 T), dry weight, of sludge annually. Using the typical rates shown in Table 4-3, a very rough estimate of the area required for agricultural utilization would be 90 ha (220 ac), plus additional area required, if any, for buffer zones, sludge storage, etc. For the same quantity of sludge utilized for land reclamation, the typical values shown in Table 4-3 indicate that 9 ha (22 ac) would be required each year that the reclamation program is in operation.

TABLE 4-3
ESTIMATED SLUDGE APPLICATION IN DRY WEIGHT FOR DIFFERENT LAND DISPOSAL OPTIONS

Disposal Option	Time Period of Application	Reported Range of Application Rates		Typical Rate	
		mt/ha	T/ac	mt/ha	T/ac
Agricultural Utilization	Annual	2-70	1-30	11	5
Forest Utilization	One time, or at 3-5 year intervals	10-220	4-100	44	20
Land Reclamation Utilization	One time	7-450	3-200	112	50
Dedicated Disposal Site	Annual	220-900	100-400	340	150

Note: The rates shown are only for the sludge application area, and do not include area for buffer zone, sludge storage, or other project area requirements.

4.5 Transportation of Sludge

Chapter 10 of this manual discusses sludge transportation alternatives and costs. Transport can be a major cost of a land application system, and requires a thorough analysis. This section is intended only to provide a brief summary of the alternatives which may be considered during the preliminary planning phase.

The first consideration is the nature of the sludge itself. As shown in Table 4-4, sewage sludge is classified for handling/transport purposes as either liquid, sludge cake, or dried, depending upon its solids content. Only liquid sludge can be pumped and transported by pipeline. If liquid sludge is transported by truck, rail, or barge, closed vessels must be used, e.g., tank truck, railroad tank cars, etc. Sludge cake can be transported in watertight boxes, and dry sludge can be transported in open boxes (e.g., dump trucks).

TABLE 4-4
SLUDGE SOLIDS CONTENT AND HANDLING CHARACTERISTICS

Sludge Type	Typical Solids Content (%)	Handling/ Transport Methods
Liquid	1 to 10	Gravity flow, pump, pipeline, tank transport
Sludge cake ("wet" solids)	15 to 30	Conveyor, auger, truck transport (watertight box)
Dried	50 to 95	Conveyor, bucket, truck transport (box)

There are four basic modes of sludge transport: truck, pipeline, barge, and railroad. In certain instances, combined transport methods (e.g., pipeline-truck, pipeline-barge) are also used. Some practical considerations of hauling sludge are presented in Tables 4-5, 4-6, and 4-7.

A rating of transport modes in terms of reliability, staffing needs, energy requirements, and costs is given in Table 4-7. For a detailed discussion of sludge transport, see Section 10.2.

4.6 Climate

Analysis of climatological data is an important consideration for the preliminary planning phase. Rainfall, temperature, evapotranspiration, and wind may be important climatic factors affecting land application of sewage sludge, selection of land application option, site management, and costs. Table 4-8 highlights the potential impacts of some climatic regions on the land application of sludge.

Meteorological data are available for most major cities from three publications of the National Oceanic and Atmospheric Administration (NOAA):

- The Climatic Summary of the United States.
- The Monthly Summary of Climatic Data, which provides basic data, such as total precipitation, maximum and minimum temperatures, and relative humidity for each day of the month, and for every weather station in the same given area. Evaporation data are also given, where available.
- Local Climatological Data, which provides an annual summary with comparative data for a relatively small number of major weather stations.

This information can be obtained by written request to NOAA, 6010 Executive Boulevard, Rockville, Maryland 20852. Another excellent source is the National Climatic Center in Asheville, North Carolina 28801. Weather data may also be obtained from local airports, universities, military installations, agricultural and forestry extension services, agricultural and forestry experiment stations, and agencies managing large reservoirs.

4.7 Sources of Additional Information

Additional sources of information on land characteristics, cropping patterns, and other relevant data include:

- U.S. Department of Agriculture - Agricultural Stabilization and Conservation Service, Soil Conservation Service, Forest Service, and Extension Service.

TABLE 4-5
TRANSPORT MODES FOR SLUDGES

Sludge Type	Transportation Considerations
Liquid Sludge	
Rail Tank Car	100-wet-ton (24,000-gal) capacity; suspended solids will settle while in transit.
Barge	Capacity determined by waterway; Chicago has used 1,200-wet-ton (290,000-gal) barges. Docking facilities required.
Pipeline	Need minimum velocity of 1 fps to keep solids in suspension; friction decreases as pipe diameter increases (to the fifth power); buried pipeline suitable for year-round use. High capital costs.
Vehicles	
Tank Truck	Capacity - up to maximum load allowed on road, usually 6,600 gal maximum. Can have gravity or pressurized discharge. Field trafficability can be improved by using flotation tires at the cost of rapid tire wear on highways.
Farm Tank Wagon and Tractor	Capacity - 800 to 3,000 gal. Principal use would be for field application.
Semisolid or Dried Sludge	
Rail Hopper Car	Need special unloading site and equipment for field application.
Truck	Commercial equipment available to unload and spread on ground; need to level sludge piles if dump truck is used. Spreading can be done by farm manure spreader and tractor.
Farm Manure Spreader	

TABLE 4-6
AUXILIARY FACILITIES FOR TRANSPORT (11)

	Transport Mode			
	Truck	Railroad	Barge	Pipeline
Liquid				
Loading storage	No*	Yes	Yes	Yes
Loading equipment	Yes	Yes	Yes	Yes
Dispatch office	Yes	Yes	Yes	NA†
Dock and/or control building	NA	NA	Yes	Yes
Railroad siding(s)	NA	Yes	NA	NA
Unloading equipment	Yes	Yes	Yes	NA
Unloading storage#	No	Yes	Yes	Yes
Dewatered				
Loading storage	Yes**	Yes	NA	NA
Loading equipment	Yes	Yes	NA	NA
Dispatch office	Yes	Yes	NA	NA
Dock and/or control building	NA	NA	NA	NA
Railroad siding(s)	NA	Yes	NA	NA
Unloading equipment	Yes	Yes	NA	NA
Unloading storage	No	No	NA	NA

* Storage required for one or two truckloads is small compared with normal plant sludge storage.

† Not applicable.

# Storage assumed to be a part of another unit process.

** Elevated storage for ease of gravity transfer to trucks.

TABLE 4-7
EVALUATION OF SLUDGE TRANSPORT MODES (11)

Characteristics	Transport Mode Alternatives					
	Truck/Barge	Pipe/Barge	Barge	Railroad	Truck	Pipeline
Reliability and Complexity*	2	2	3	1	1	3
Staffing Skills†	3	3	3	2	1	3
Staff Attention (Time)#	4	3	4	1	3	2
Applicability and Flexibility**	3	3	3	2	1	3
Energy Used††	7	3	5	2	8	6
Costs						
Capital Investment	High	High	High	-	Low	High
Operation, Maintenance, and Labor	High	Moderate	Moderate	-	Fairly High	Low
Overall##	--	--	--	Generally High***	--	--

* 1 = most reliable, least complex; 2 = intermediate; 3 = least reliable, most complex.

† 1 = least skills; 2 = intermediate; 3 = highest skills.

Attention time increases with magnitude of number.

** 1 = wide applicability (all types of sludges); 3 = limited applicability, relatively flexible.

†† 1 = lowest; 8 = highest.

## Overall costs are a function of sludge quantities and properties (percent solids), distance transported, and need for special storage loading and unloading equipment.

*** Rail costs would generally be in the form of freight charges; costs could be lower for large volumes of sludge.

TABLE 4-8
POTENTIAL IMPACTS OF CLIMATIC REGIONS ON LAND APPLICATION OF SLUDGE (11)

Impact	Climatic Region		
	Warm/Arid	Warm/Humid	Cold/Humid
Operation Time	Year-round	Seasonal	Seasonal
Operation Cost	Lower	Higher	Higher
Storage Requirement	Less	More	More
Salt Buildup Potential	High	Low	Moderate
Leaching Potential	Low	High	Moderate
Runoff Potential	Low	High	High

- U.S. Geological Survey.
- U.S. EPA.
- U.S. Corps of Engineers offices.
- Private photogrammetry and mapping companies.
- State agricultural mining and geologic agencies.
- State water resources agencies.
- State universities and local colleges.
- Local planning and health departments.
- Local water conservation districts.
- Ground water users (municipalities, water companies, individuals, etc.).
- State land grant universities and water resource centers.

4.8 References

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CHAPTER 5

SITE EVALUATION AND SELECTION OF OPTIONS

5.1 General

This chapter is designed to assist in the identification, evaluation, and selection of sites for the land application of sludge, and in the selection of a final land application option(s). At this point, the user should have reviewed the preceding chapters and have done the following:

1. Estimated the present and future quantity, physical characteristics, and chemical quality of the sludge(s) being considered for land application.
2. Reviewed the pertinent federal, state, and local regulations which apply to the project under consideration. Preferably, this will have included a discussion with the regulatory agencies involved.
3. Compared the data developed above, and determined that there are no insurmountable problems with the sludge quality in terms of its suitability for land application.
4. Recognized that the public participation process (Chapter 3) is critical to project success, and established a public participation/education program.
5. Reviewed the definitions of the four land application options covered by this manual, and the general advantages, disadvantages, constraints, etc., applicable to each option (see Chapter 2 and Table 2-1). Based on this knowledge, the designer should have eliminated the land application options that are clearly not feasible for the local situation.
6. Made a rough estimate of the land area required for each of the remaining land application options (see Section 4.4 and Table 4-3).
7. Reviewed in a general way alternatives for sludge transport, and recognized the impact of sludge transport costs upon overall project costs.

The careful identification, evaluation, and ultimate selection of land application sites can prevent future environmental problems, reduce monitoring requirements, minimize overall program costs, and moderate or eliminate adverse public reaction. Poor site selection and management practices in the past have resulted in environmental problems and public resistance.

5.1.1 Planning Procedure

As shown in Figure 5-1, a two-phase planning approach is suggested to avoid unnecessary effort and expense. The first phase involves a screening process by review of available information and experience. If potential sites are identified for any of the land application options under consideration, the process moves into the second phase which includes field investigations of potential sites and detailed evaluation of alternatives.

If more than one site and/or application option seems possible, a detailed evaluation of each concept and the related costs will assist in determining the optimum combination of site(s) and option(s).

5.2 Land Use in the Area

Prevailing or projected land use often exerts a significant influence on site selection, as well as acceptance of a particular sludge application option. It is necessary to determine both current and future land use in assessing the land area potentially suitable and/or available for sludge application. Important considerations include zoning compliance, aesthetics, and site acquisition.

5.2.1 Current Land Use

Current land use patterns will help identify areas where land application of sludge may or may not be acceptable. The local Soil Conservation Service (SCS) and Agricultural Extension Service representatives have knowledge of local farming, forestry, mining, and other land use practices. The SCS will, in many cases, have a comprehensive county soil survey with aerial photo maps showing the land area.

5.2.1.1 Agricultural Utilization

To a great extent, prevailing farming practices dictate the acceptability of this option. Small land holdings in a nonagricultural community may limit the agricultural sludge application options. An area devoted almost exclusively to production of human food crops restricts the periods when sludge can be applied to land. Areas with row crops, small grains, hay crops, and pastures make it possible to apply sludge throughout much of the year.

5.2.1.2 Forested Lands

A consideration in the application of sludge to forest lands is the potential need to control public access for a period of time after sludge application. Therefore, in screening current land use data for potential sites to apply sludge to forest land, the most desirable sites are often those owned by or leased to commercial growers, which already control public access. Publicly owned forest land has been used for sludge application, but may require complex interagency negotiations and greater public education efforts than the use of privately owned land.

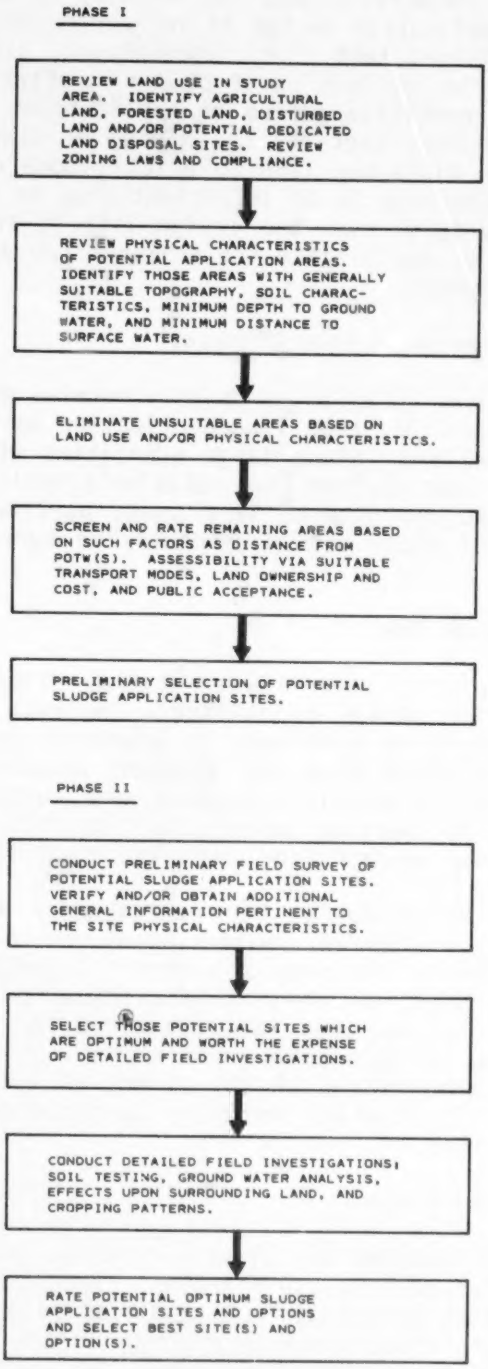
PHASE I
REVIEW LAND USE IN STUDY AREA. IDENTIFY AGRICULTURAL LAND, FORESTED LAND, DISTURBED LAND AND/OR POTENTIAL DEDICATED LAND DISPOSAL SITES. REVIEW ZONING LAWS AND COMPLIANCE.
REVIEW PHYSICAL CHARACTERISTICS OF POTENTIAL APPLICATION AREAS. IDENTIFY THOSE AREAS WITH GENERALLY SUITABLE TOPOGRAPHY, SOIL CHARACTERISTICS, MINIMUM DEPTH TO GROUND WATER, AND MINIMUM DISTANCE TO SURFACE WATER.
ELIMINATE UNSUITABLE AREAS BASED ON LAND USE AND/OR PHYSICAL CHARACTERISTICS.
SCREEN AND RATE REMAINING AREAS BASED ON SUCH FACTORS AS DISTANCE FROM POTW(S). ASSESSIBILITY VIA SUITABLE TRANSPORT MODES, LAND OWNERSHIP AND COST, AND PUBLIC ACCEPTANCE.
PRELIMINARY SELECTION OF POTENTIAL SLUDGE APPLICATION SITES.
PHASE II
CONDUCT PRELIMINARY FIELD SURVEY OF POTENTIAL SLUDGE APPLICATION SITES. VERIFY AND/OR OBTAIN ADDITIONAL GENERAL INFORMATION PERTINENT TO THE SITE PHYSICAL CHARACTERISTICS.
SELECT THOSE POTENTIAL SITES WHICH ARE OPTIMUM AND WORTH THE EXPENSE OF DETAILED FIELD INVESTIGATIONS.
CONDUCT DETAILED FIELD INVESTIGATIONS; SOIL TESTING, GROUND WATER ANALYSIS, EFFECTS UPON SURROUNDING LAND, AND CROPPING PATTERNS.
RATE POTENTIAL OPTIMUM SLUDGE APPLICATION SITES AND OPTIONS AND SELECT BEST SITE(S) AND OPTION(S).

Figure 5-1. Two-phase approach to sludge application site identification, evaluation and selection.

5.2.1.3 Drastically Disturbed Lands

Disturbed sites are relatively easy to identify in a particular local area. The sludge application design is influenced by the potential future use of the reclaimed land (i.e., agriculture, silvaculture, parks, greenbelts, etc.). The application of sludge is often a one-time operation rather than a repetitive series of applications on the same site. It is therefore necessary that (1) the mining or other operations will continue to generate disturbed land to which sludge can be applied, or (2) the disturbed land area is of sufficient size to allow a continuing sludge application program over the design life of the project. State and federal guidelines may dictate the criteria for sludge applications and subsequent management.

5.2.1.4 Dedicated Land Disposal

Dedicated land disposal (DLD) sites usually receive much greater sludge application rates than the other land application options, so land area requirements are smaller. Since large quantities of sludge are being transported, stored, and applied in a relatively small area, this option is very sensitive to surrounding land uses, particularly housing and commercial uses. DLD sites should generally be surrounded by areas of limited public use.

5.2.2 Future Land Use

Projected land use plans, where they exist, may eliminate certain areas from consideration for sludge application. Regional planners and planning commissions should be consulted to determine the projected use of potential land application sites and adjacent properties. If the site is located in or near a densely populated area, extensive control measures may be needed to overcome concerns and minimize potential aesthetic problems which may detract from the value of adjacent properties.

Future development of potential land application sites and adjacent properties should be considered. Master plans for the existing communities should be examined. The rate of industrial and/or municipal expansion relative to prospective sites can significantly affect their long-term suitability. For example, land dedicated for sludge disposal at high rates might not be appropriate for either agricultural use or for suburban home developments due to the effect of accumulated metals on garden food crops. It is often necessary to place deed restrictions on future use of DLD sites.

5.2.3 Zoning Compliance

Zoning and land use planning are closely related, and zoning ordinances generally reflect future land use planning. Applicable zoning laws, if any, which may affect potential land application sites should be reviewed concurrent with land use evaluations. Since it is unusual that a community will have a specific area zoned for sludge/waste disposal, project proponents normally will have to seek a zoning change for a DLD site. The same is true for separate sludge storage facilities.

5.2.4 Aesthetics

Selection of a land application site and/or sludge application option can be affected by community concern over aesthetics, such as noise, fugitive dust, and odors. In addition to application site area concerns, routes for sludge transport vehicles must be carefully evaluated in terms of avoiding residential areas, bridge load limitations, etc. Disruption of the local scenic character and/or recreational activities, should they occur, may generate strong local opposition to a sludge management program. Obviously, every attempt must be made to keep the application site compatible with its surroundings and, where possible, enhance the beauty of the landscape. Buffer zones are often provided around DLD sites, and are also usually required to separate sludge application sites from residences, water supplies, surface waters, roads, parks, playgrounds, etc.

5.2.5 Site Acquisition

Application of sludge to agricultural land can usually be accomplished without direct purchase or lease acquisition of land. Well-prepared educational and public participation programs early in the planning stages normally identify numerous farmers willing to cooperate with the city in a land application program. Experience nationwide has shown that cooperation of this type is often less disruptive within a community, and frequently more likely to achieve public acceptability than land purchase.

Several different contractual arrangements between cities and landowners for agricultural utilization have been successfully employed, including:

- The city transports and spreads the sludge at no expense to the landowner.
- The city transports and spreads the sludge, and pays the landowner for the use of his land.
- The landowner pays a nominal fee for the sludge and for the city to transport and spread the sludge. This is most common for agricultural utilization where there is local demand for sludge as a fertilizer or soil conditioner.
- The city hauls the sludge and the landowner spreads it.
- The landowner hauls and spreads the sludge.

A written contract between the landowner and the sewage sludge applicator is highly recommended. In some instances, the applicator will be the municipality; in other cases, it will be a private applicator who is transporting and spreading for the municipality.

The principal advantage of a written contract is to ensure that both parties understand the agreement prior to applying the sludge. Often, oral contracts are entered with the best of intentions, but the landowner and applicator have differing notions of the rights and obligations of each party. In some cases, the contract may serve as evidence in disputes concerning the performance of either the applicator or the landowner. Suggested provisions of contracts between the applicator and landowner are shown in Table 5-1 (4).

TABLE 5-1
SUGGESTED PROVISIONS OF CONTRACTS BETWEEN SLUDGE GENERATOR, SLUDGE APPLICATOR, AND PRIVATE LANDOWNERS (4)

1. Identification of the landowner, the POTW, and the applicator spreading the sludge.
2. Location of land where spreading is to occur and boundaries of the application sites.
3. Entrance and exit points to application sites for use by spreading equipment.
4. Specification of the range of sludge quality permitted on the land. Parameters identified might include percent of total solids and levels of Zn, Cu, Ni, Pb, Cd, N, P, K, and trace elements in the sludge. The contract would specify who is to pay for the analysis and frequency of analysis.
5. Agreement on the timing of sludge application during the cropping season. Application rates and acceptable periods of application should be identified for growing crops, as well as periods when the soil is wet.
6. Agreements on the application rate. This rate might vary throughout the year depending on the crop, the sludge analyses, and when and where application is occurring.
7. Restrictions on usage of land for root crops, fresh vegetables, or livestock production.
8. Conditions under which either party may escape from provisions of the contract.

The use of land without purchase or leasing may also find applicability for land application of sludge to disturbed and forested lands. However, direct purchase or lease may be necessary for large city sludge programs regardless of the land application option. In these instances, site acquisition represents a major cost in the implementation of the land application program.

5.3 Physical Characteristics of Potential Sites

The physical characteristics of concern are:

- Topography.
- Soil permeability, infiltration, and drainage patterns.

- Depth to ground water.
- Proximity to surface water.

The planner/designer should review state regulations or guidelines that place limits on these physical characteristics of application sites.

5.3.1 Topography

Topography influences surface and subsurface water movement which affects the amount of soil erosion and potential runoff of applied sludge. Topography can indicate the kinds of soil to be found on a site.

Soils on ridge tops and steep slopes are typically well drained, well aerated, and usually shallow. Except on very permeable soils, steep slopes increase the possibility of surface runoff of sludge. Soils on concave land positions and on broad flat lands frequently are poorly drained, and may be waterlogged during part of the year. The soils between these two extremes will usually have intermediate properties with respect to drainage and runoff.

The steepness, length, and shape of slopes influence the rate of runoff from a site. Rapid surface runoff accompanied by soil erosion can erode sludge-soil mixtures and transport them to surface waters. Therefore, many existing state regulations/guidelines stipulate the maximum slopes allowable for sludge application sites under various conditions, such as sludge physical characteristics, application techniques, and application rates. Specific guidance should be obtained from the regulatory agency; for general guidance, suggested limits are presented in Table 5-2.

TABLE 5-2
RECOMMENDED SLOPE LIMITATIONS FOR LAND APPLICATION
OF SLUDGE (COMPILED FROM TYPICAL EXISTING STATE REGULATIONS IN 1982)

Slope	Comment
0-3%	Ideal; no concern for runoff or erosion of liquid sludge or dewatered sludge.
30-6%	Acceptable; slight risk of erosion; surface application of liquid sludge or dewatered sludge okay.
6-12%	Injection of liquid sludge required for general cases, except in closed drainage basin and/or extensive runoff control. Surface application of dewatered sludge is usually acceptable.
12-15%	No liquid sludge application without effective runoff control; surface application of dewatered sludge acceptable, but immediate incorporation recommended.
Over 15%	Slopes greater than 15% are only suitable for sites with good permeability where the slope length is short and is a minor part of the total application area.

5.3.2 Soil Permeability, Infiltration, and Drainage

The texture of the soil and parent geologic material is one of the most important aspects of site selection, because it influences permeability, infiltration, and drainage. Appendix B includes a detailed discussion of soil characteristics relative to sludge application; it is important that a qualified soil scientist be involved in the assessment of soils at potential sludge application sites.

With proper design and operation, sludge can be successfully applied to virtually any soil. However, highly permeable soil (e.g., sand), highly impermeable soil (e.g., clay), or poorly drained soils may present special design and operation problems. Therefore, sites with such conditions should generally be given a lower priority during the preliminary site selection process. Table 5-3 summarizes typical guidelines for soil suitability. In some cases, the favorable aspects (i.e., location, municipal ownership, etc.) may outweigh the costs of mitigation measures.

5.3.2.1 Soil Permeability and Infiltration

Permeability (a property determined by soil pore space and size, shape, and distribution) refers to the ease with which water and air are transmitted through soil. Appendix B discusses these soil characteristics in detail. Fine-textured soils generally possess slow or very slow permeability, while those of coarse-textured soils range from moderately rapid to very rapid. A medium-textured soil, such as a loam or silt loam, tends to have moderate to slow permeability. The Soil Conservation Service (SCS) has defined permeability classes for use in describing soils (6), as listed in Table 5-4.

5.3.2.2 Drainage Patterns

In selecting a site for sludge utilization, a landscape consisting of or approaching a closed drainage system may be desirable for containment of the sludge (Figure 5-2).

The selection of a DLD site should be confined to a closed drainage system. Whether natural or man-made, a series of protective ridges, berms, underdrains, or other physical barriers should be provided to contain the sludge within the site perimeter.

The U.S. SCS drainage classes are shown in Table 5-5. Very poorly drained, poorly drained, and somewhat poorly drained classes are seldom suitable for sludge application unless adequate surface or subsurface tile drainage is provided (2)(5). These soils are prone to flooding and surface ponding. Moderately well drained, well drained, and somewhat excessively drained soils are generally suitable for waste application, with the well drained soils offering the greatest potential for waste renovation. Typically, a well drained soil is at least moderately permeable (Table 5-4).

TABLE 5-3
SOIL LIMITATIONS FOR SEWAGE SLUDGE TO AGRICULTURAL LAND AT NITROGEN FERTILIZER RATES IN WISCONSIN (13)

Soil Features Affecting Use	Degree of Soil Limitation		
	Slight	Moderate	Severe
Slope*	Less than 6%	6 to 12%	More than 12%
Depth to seasonal water table	More than 1.2 m	0.6 to 1.2 m	Less than 0.61 m
Flooding and ponding	None	None	Occasional to frequent
Depth to bedrock	More than 1.2 m	0.6 to 1.2 m	Less than 0.61 m
Permeability of the most restricting layer above a 1-m depth	0.24 to 0.8 cm/hr	0.8 to 2.4 cm/hr 0.08 to 0.24 cm/hr	Less than 0.08 cm/hr More than 2.4 cm/hr
Available water capacity	More than 2.4 cm	1.2 to 2.4 cm	Less than 1.2 cm

* Slope is an important factor in determining the runoff that is likely to occur. Most soils on 0 to 6% slopes will have slow to very slow runoff; soils on 6 to 12% slopes generally have medium runoff; and soils on steeper slopes generally have rapid to very rapid runoff.

Metric conversions:

1 ft = 0.3048 m
1 in = 2.54 cm.

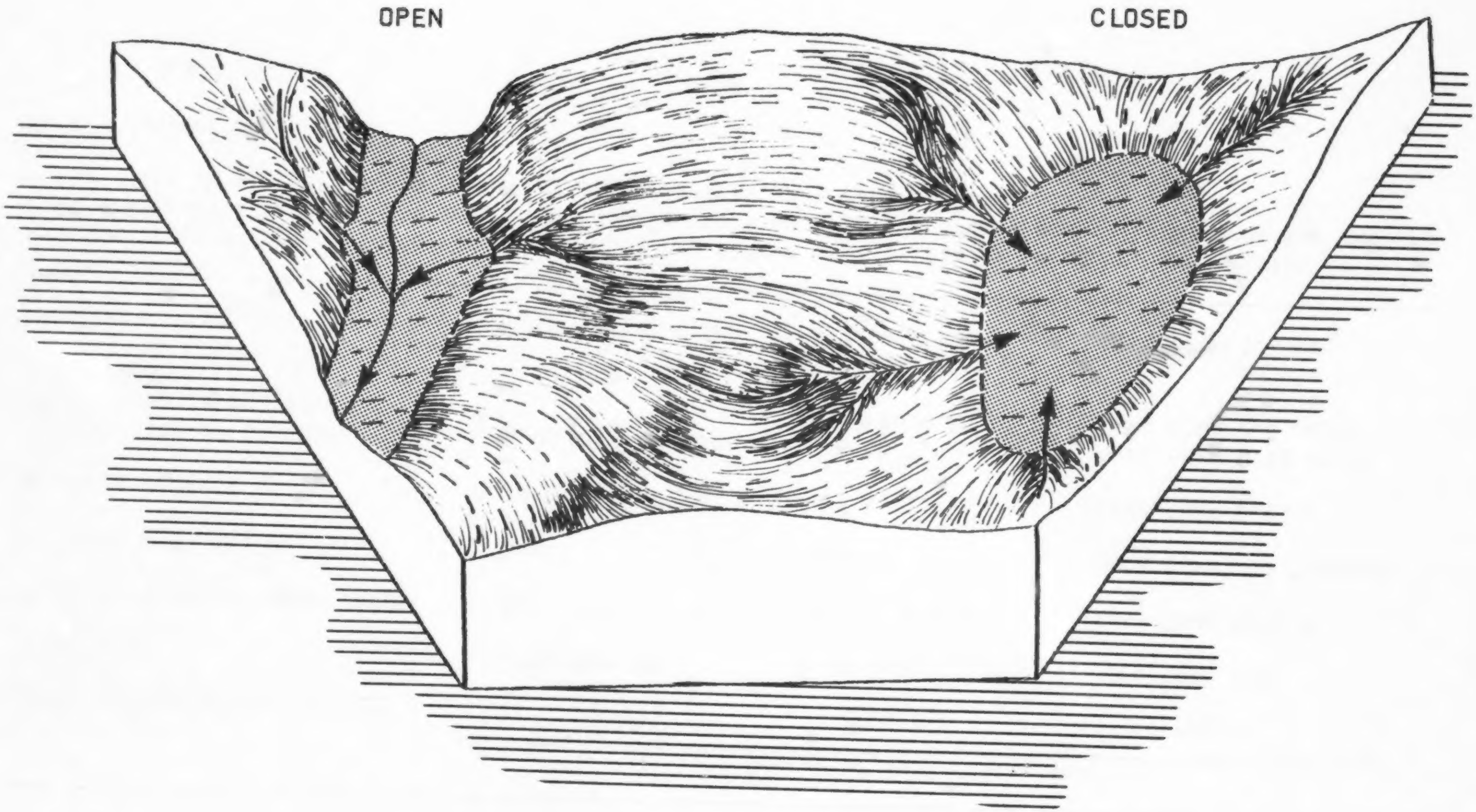

Figure 5-2. Diagrammatic representation of open and closed drainage systems.

TABLE 5-4
SOIL CONSERVATION SERVICE (SCS) PERMEABILITY CLASSES FOR SATURATED SOIL (6)

Soil Permeability (cm/hr)	Class
<0.15	Very slow
0.15 to 0.5	Slow
0.5 to 1.5	Moderately slow
1.5 to 5.1	Moderate
5.1 to 15.2	Moderately rapid
15.2 to 51	Rapid
>51	Very rapid

TABLE 5-5
SOIL CONSERVATION SERVICE (SCS) DRAINAGE CLASSES (6)

Drainage Class	Observable Symptom
Very poorly drained	Water remains at or on the surface most of the year.
Poorly drained	Water remains at or near the surface much of the year.
Somewhat poorly drained	Soils are wet for significant portions of the year.
Moderately well drained	Soils are seasonally wet (e.g., high water table in spring).
Well drained	Water readily removed from the soil either by subsurface flow or percolation; optimum condition for plant growth.
Somewhat excessively drained	Water is rapidly removed from the soil; characteristic of many uniform sands.
Excessively drained	Very rapid removal of water with little or no retention.

Excessively drained soils provide rapid water flow, and their use for sludge application may be restricted except under the following conditions:

- Sludge application at very low rates. Some states will allow sludge to be applied to any soil at very low rates, e.g., <2.2 mt/ha (1 T/ac), dry weight.
- Sludge application sites over exempted aquifers. Some ground water aquifers are considered unacceptable for potable uses because of poor quality, and are exempted from regulations protecting against ground water degradation.

5.3.3 Ground Water Constraints

In preliminary screening of potential sites, it is necessary to consider ground water information from the application area:

- Depth to ground water (including historical highs and lows).
- Ground water quality and use classification by regulatory authorities.
- An estimate of ground water flow patterns.

When a specific site or sites has been selected for sludge application, a detailed field investigation may be necessary to determine the above information. During preliminary screening, however, published general resources may be located at local USGS or state water resource agencies.

Generally, the greater the depth to the water table, the more desirable a site is for sludge application. Sludge should not be placed where there is potential for direct contact with the ground water table. The actual thickness of unconsolidated material above a permanent water table constitutes the effective soil depth. The desired soil depth may vary according to sludge characteristics, soil texture, soil pH, method of sludge application, and sludge application rate. Table 5-6 summarizes recommended criteria for the various sludge application options.

The kind and condition of consolidated material above the water table is also of major importance for high-rate sludge application systems. Fractured rock may allow leachate to move rapidly with little opportunity for contaminant removal. On the other hand, unfractured bedrock at shallow depths will restrict water movement, with the potential for ground water mounding, subsurface lateral flow, or poor drainage. Limestone bedrock is of particular concern where sinkholes may exist. Sinkholes, like fractured rock, can accelerate the movement of leachate to ground water. Potential sites with potable ground water in areas underlain by fractured bedrock at shallow depths, or sites containing limestone sinkholes should be avoided. Major ground water recharge zones that recharge major aquifers with existing or potential use for drinking water should probably be excluded from consideration.

TABLE 5-6
RECOMMENDED LIMITS FOR DEPTH TO GROUND WATER

Type of Site	Drinking Water Aquifer	Excluded Aquifer*
Agricultural	1 m	0.5 m
Forest	2 m†	0.7 m
Drastically Disturbed Land	1 m#	0.5 m
Dedicated Land Disposal	At least 3 m	0.5 m

* Clearances are to ensure trafficability of surface, not for ground water protection.

† Seasonal (springtime) high water and/or perched water less than 1 m is not usually a concern (see design chapter for discussion of these limits).

# Assumes no ground water contact with leachate from operation.

Metric Conversion: 1 m = 3.28 ft.

5.3.4 Proximity to Surface Water

The number, size, and nature of surface water bodies on or near a potential sludge application site are significant factors in site selection due to potential contamination from site runoff and/or flood events. In general, areas subject to frequent flooding have severe limitations for disposal of wastes. Engineered flood control structures can be constructed to protect a sludge application site against flooding. Because such structures are expensive, this use is usually only applicable for a high-rate, long-term DLD site. Table 5-7 presents typical setback distances for sludge application operations.

5.4 Site Selection Process

The selection process for sludge application sites involves the evaluation of physical, chemical, economic, and social characteristics. The information is organized to progressively eliminate unfeasible sites. There are five steps in the procedure:

- Initial site screening.
- Field site survey.
- Field investigations and testing.
- Economic feasibility.
- Final site selection.

TABLE 5-7
SUGGESTED SETBACK DISTANCES FOR SLUDGE APPLICATION AREAS (16)

Feature	Distance from Feature to Sludge Application Site				
	15 to 90 m*		90 to 460 m†		>460 m#
	Injection**	Surface	Injection**	Surface	Injection and Surface
Residential development	No	No	Yes	No	Yes
Inhabited dwelling	Yes	No	Yes	Yes	Yes
Ponds and lakes	Yes	No	Yes	Yes	Yes
Springs	No	No	Yes	Yes	Yes
10-year high water mark of streams, rivers, and creeks	Yes	No	Yes	Yes	Yes
Water supply wells	No	No	Yes	Yes	Yes
Public road right-of-way	Yes	No	Yes	Yes	Yes

* 50 to 300 feet.

† 300 to 1,500 feet.

# >1,500 feet.

** Injection of liquid sludge or surface application of dewatered sludge.

5.4.1 Site Screening

Site screening requires:

- An estimate of land area required for each utilization/disposal option considered.
- Elimination of unsuitable areas due to physical, environmental, social, or political reasons.

5.4.1.1 Estimate Land Area Required

Preliminary estimates of land area required for each of the alternate sludge utilization/disposal options can be determined from data presented in Table 4-3 in Chapter 4. More precise land area requirements are needed for design. The values from Table 4-3 should be adequate for preliminary planning.

5.4.1.2 Eliminate Unsuitable Areas

Soil survey reports can be obtained from the local SCS offices; these surveys are suitable for preliminary planning. When some potential sites are identified, field inspections and investigations are necessary to confirm expectations. The SCS mapping units cannot represent areas smaller than 0.8 to 1.2 ha (approximately 2 to 3 acres). Thus, there is a possibility that small areas of soils with significantly different characteristics may be located within a mapping unit but not identified.

Quadrangles published by the U.S. Geological Survey may be useful during preliminary planning and screening in estimating slope, topography, local depressions or wet areas, rock outcrops, regional drainage patterns, and water table elevations. These maps are usually drawn to a scale of 1:24,000 (7.5-minute series) or 1:62,500 (15-minute series). Because of their scale, they too cannot be relied upon for evaluating small parcels, and do not eliminate the need for field investigation of candidate sludge application sites. The use of regional maps and soil survey maps can help eliminate potentially unsuitable areas. Table 5-8 summarizes important criteria.

TABLE 5-8
POTENTIALLY UNSUITABLE AREAS FOR SLUDGE APPLICATION

1. Land adjacent to subdivisions, schools, and other inhabited dwellings.
2. Areas bordered by ponds, lakes, rivers, and streams without appropriate buffer areas.
3. Wetlands and marshes.
4. Steep areas with sharp relief.
5. Undesirable geology (karst, fractured bedrock) (if not covered by a sufficiently thick soil column).
6. Undesirable soil conditions (shallow, permafrost).
7. Areas of historical or archeological significance.
8. Other environmentally sensitive areas such as floodplains or intermittent streams, ponds, etc.
9. Rocky, nonarable land.

One practical screening technique involves the use of transparent (mylar) overlays with concentric rings drawn around the POTW(s). The distance represented by the initial ring will vary depending on POTW location, sludge quantity, proximity of nearby communities, local topography, and the application option(s) being considered. A small community might start with an area 20 km (12.5 miles) in diameter, while a large system may initially screen a much larger study area. Shaded areas representing unsuitable locations are marked on the map or the transparency. If the initial ring does not have suitable sites, then the next ring with a larger diameter should be considered. It should be remembered that areas which are unsuitable in their existing state can often be modified to make them acceptable for sludge application. The necessary modifications (e.g., extensive grading, drainage structures, flood control, etc.) may be cost-effective if the site is otherwise attractive in terms of location, low land cost, etc.

5.4.2 Contact with Owners of Prospective Sites

When potential sites are identified, ownership should be determined. Often the City Hall, County Courthouse, or a real estate broker will have community or areawide maps indicating the tracts of land, present owners, and property boundaries. The County Recorder and title insurance companies are also useful sources of information on property ownership, size of tracts, and related information. Contacting landowners prematurely without adequate preparation may result in an initial negative reaction which is difficult to reverse. The public information program should be prepared, and local political support secured. The individuals involved in making the initial owner contacts should be knowledgeable about potential program benefits and constraints (see Chapter 3).

Initial contacts concerning the proposed project should be made with the prospective landowners/site managers through personal interviews. Initial contacts via telephone are not recommended to avoid misunderstandings regarding the benefits of any such program.

5.4.3 Field Site Survey

When the map study has identified potential sites, a field site survey should be conducted. A drive or walk through the candidate areas should verify or provide additional information on:

- Topography - Estimate of slope both on prospective site and adjacent plots.
- Drainage - Open or closed drainage patterns.
- Distance to surface water.
- Distance to water supply well(s).
- Available access roads - All-weather or temporary.
- Existing vegetation/cropping.

A field survey form similar to the one shown in Table 5-9 which records the current condition of all critical factors is recommended. The data sets collected from various sites can then be used to update the map overlay.

TABLE 5-9
SAMPLE FORM FOR PRELIMINARY FIELD SITE SURVEY

A. PROPERTY LOCATION ____________________ PROPERTY OWNER ____________________

B. TOPOGRAPHY

1. Relief (sharp, flat, etc.)____________________
2. Slope Estimate____________________
3. Drainage Patterns
   - Open/Closed____________________
   - Drainage Class No.*____________________
   - Any Underdrains____________________

C. DISTANCE FROM SITE BOUNDARY TO:

1. Surface Water____________________
2. Water Supply Well____________________

D. ESTIMATE OF SITE DIMENSIONS

1. Area____________________
2. Natural Boundaries____________________
3. Fences____________________

E. AVAILABLE ACCESS

1. Road Types____________________
2. Other____________________

F. EXISTING VEGETATION/CROPS AND COMMONLY USED CROP ROTATIONS

1. On-Site____________________
2. Neighboring Properties____________________

G. SOIL

1. Texture____________________
2. Variability____________________

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* Refer to Table 5-5 for drainage class.

5.5 Field Investigation and Testing

5.5.1 General

The extent of field investigations will vary depending on:

- Land application option(s) being considered, e.g., agricultural, forest, land reclamation, or dedicated disposal site (see Table 5-10).
- Regulatory requirements.
- Completeness and suitability of soils, topographic, hydrogeologic information obtained from other sources, e.g., the SCS, USGS, etc.

Table 5-10 provides a summary of the site-specific information required. This information is of a general nature and can usually be obtained without field sampling and testing. Review of this information may eliminate some potential sites from further consideration.

5.5.2 Soil Testing

Soil test data and site characteristics normally needed when evaluating sludge land application options are summarized in Table 5-11. Chemical soil testing methodologies are discussed in Appendix C. Additional procedural information may be obtained from the local SCS, extension services universities, laboratories, and consultants. Appendix B discusses soil properties in detail.

5.5.2.1 Soil Chemical Properties

Determinations of pH, lime requirement, and cation exchange capacity (CEC) are generally needed to assess appropriate sludge application rates and site management practices. Soil pH and to some extent CEC influence the soil's ability to attenuate heavy metal cations (18). The CEC is determined to a large extent by the organic matter content and the amount and kind of clay content in soil. Generally, soils with higher CEC values are more efficient at retaining heavy metals, and are therefore more desirable for a sludge utilization/disposal site.

When agricultural, forestry, and reclamation utilization options are considered, soil fertility tests are sometimes desirable in determining the amount of supplemental fertilizer that may be needed to optimize crop growth. These analyses, except for pH, are generally not needed for lands dedicated for disposal. For these sites, emphasis is placed on the soil physical properties, and engineering design is usually geared toward pollution control, rather than agricultural productivity.

TABLE 5-10
NECESSARY SITE-SPECIFIC INFORMATION OF A GENERAL NATURE

1. Property Ownership
2. Physical Dimensions of Site
   - A. Overall boundaries
   - B. Portion usable for sludge utilization/disposal under constraints of topography, buffer zones, etc.
3. Current Land Use
4. Planned Future Land Use
5. If Agricultural Crops Are to Be Grown:
   - A. Cropping patterns
   - B. Typical yields
   - C. Methods and quantity of fertilizer application
   - D. Methods of soil tillage
   - E. Irrigation practices, if any
   - F. Final use of crop grown (animal/human consumption, non-food chain, etc.)
   - G. Vehicular access within site
6. If Forest Land:
   - A. Age of trees
   - B. Species of trees
   - C. Commercial or recreational operation
   - D. Current fertilizer application
   - E. Irrigation practices
   - F. Vehicular access within site
7. If Drastically Disturbed Land (i.e., for reclamation option):
   - A. Existing vegetation
   - B. Historical causes of disturbance, e.g., strip mining of coal, dumping of mine tailings, etc.
   - C. Previous attempts at reclamation, if any
   - D. Need for terrain modification
8. Surface/Ground Water Conditions
   - A. Location and depth of wells, if any
   - B. Location of surface water (occasional and permanent)
   - C. History of flooding and drainage problems
   - D. Seasonal fluctuation of ground water level
   - E. Quality and users of ground water

TABLE 5-11
SUGGESTED SOIL TEST DATA AND SITE CHARACTERISTICS FOR SLUDGE LAND APPLICATION OPTIONS

Field Test	Agro.	Forest	DDL	DLD
Soil Chemical Property				
• pH	Y	Y	Y	Y
• Lime Requirement	Y	Y	Y	Y
• Cation Exchange Capacity (CEC)	Y	Y	Y	Y
• Plant Available Nitrogen (N)*	Y	-	-	-
• Plant Available Phosphorus (P)	Y	-	-	-
• Plant Available Potassium (K)	Y	-	-	-
• Background Metal Analysis	Y	Y	Y	Y
• Exchangeable Sodium % (ESP)[a]	Ya	Ya	Ya	-
Soil Physical Property				
• Depth of Profile	Y	Y	Y	Y
• Texture and Structure	-b	Y	Y	Y
• Permeability	-b	Y	Y	Y
Ground Water				
• Depth	Y	Y	Y	Y
• Seasonal Fluctuation	-	Y	Y	Y
• Saturated Hydraulic Conductivity	-	Y	Y	Y
• Quality	-	Y	Y	Y
• Uses	-	Y	Y	Y
Bedrock				
• Depth	-	-	Y	Y
• Types	-	-	Y	Y
• Fractures	-	-	Y	Y

Notes:

* Soil tests for plant available N may not be available or required for all regions in the United States.

Y indicates that data are necessary for site selection and design.

- indicates data are not critical.

a = ESP may be critical for arid western states (see Reference 10 for discussion).

b = Assumed suitable for agronomic purposes.

5.5.2.2 Soil Physical Properties

Appendix B discusses the relationship between soil texture and structure, drainage, and stability characteristics. These physical properties are much less important if the site will be used for application of sludge at low rates (e.g., agricultural utilization at agronomic rates), or if dewatered or dry sludge will be applied.

5.5.3 Ground Water Testing

Field data pertinent to ground water are listed in Tables 5-10 and 5-11. Leachate formation is of little concern for low-rate agricultural sludge applications, and field testing and/or operational monitoring for ground water quality may not be required.

5.6 Preliminary Cost Analysis

A preliminary estimate of relative costs should be made as part of the site selection process. These estimates are necessary for comparing alternative sites and/or application options.

Proximity of the sludge application sites to the POTW(s) is very important in the decision-making process due to high transport costs. Further, the cost of sludge dewatering equipment may be evaluated in view of estimated fuel savings through decreased total loads and/or shorter haul distances. For ease of comparison, all costs should be expressed in dollars per dry weight of sludge. Capital costs should be estimated over the life of the site, whereas operating costs should be estimated annually. Cost factors that are of prime importance are summarized in Table 5-12. These assessments should be based on experience and best engineering judgement.

TABLE 5-12
COST FACTORS TO BE CONSIDERED DURING SITE SELECTION

Capital Costs

- Land acquisition - purchase, lease, or use of private land.
- Site preparation - grading, roads, fences, drainage, flood control, and buildings (if needed).
- Equipment - sludge transport and application.
- Sludge storage facilities.

Operating Costs

- Fuel for sludge transport and application.
- Labor (transport, application, maintenance, sampling, etc.).
- Equipment repair.
- Utilities.
- Monitoring, if required (laboratory analyses, sample containers, shipping).
- Materials and miscellaneous supplies.

5.7 Final Site Selection

The final selection of the site(s) is often a simple decision based on the availability of the best site(s). This is frequently the case for small communities. If, however, the site selection process is complex, involving many potential sites and/or several sludge utilization/disposal options, a weighted scoring system may be useful.

The use of a quantitative scoring system is demonstrated in Section 4.4 of the Process Design Manual for Municipal Sludge Landfills (11). While the criteria for selecting site(s) for the land application options discussed in this manual differ somewhat from those provided in the landfill design manual, the weighting and scoring system may be useful.

Several other considerations should be integrated into this decision-making process. These include:

- Compatibility of sludge quantity and quality with the specific land application option selected (see Chapter 4, Section 4.2, for more detail).
- Public acceptance of both the option(s) and site(s) selected.
- Anticipated design life, based on assumed application rate, land availability (capacity), projected heavy metal loading rates, and soil properties.

5.8 Selection of Land Application Options

When the most feasible land application options have been identified, preliminary estimates of site life expectancy and costs (capital and O&M) for the individual options should be made. Potential social and environmental impacts resulting from each option should also be assessed. Comparison of these data should reveal the most suitable option which fits both the needs of the POTW and local conditions. The POTW may also consider adopting more than one land application option (e.g., agricultural and forested land applications) if the combined practice appears to be cost-effective. The flow chart shown in Figure 5-3 summarizes the procedure for selecting a land treatment option.

A checklist of relevant design features for each land application option is usually helpful in compiling information, and provides baseline data for cost estimates (see Table 5-13). Comparison and evaluation of individual options may be based on both quantitative and qualitative factors:

- Estimated costs.
- Potential environmental impacts (adverse and beneficial).
- Potential public health impacts.
- Reliability.
- Flexibility.
- Land area requirements and availability.

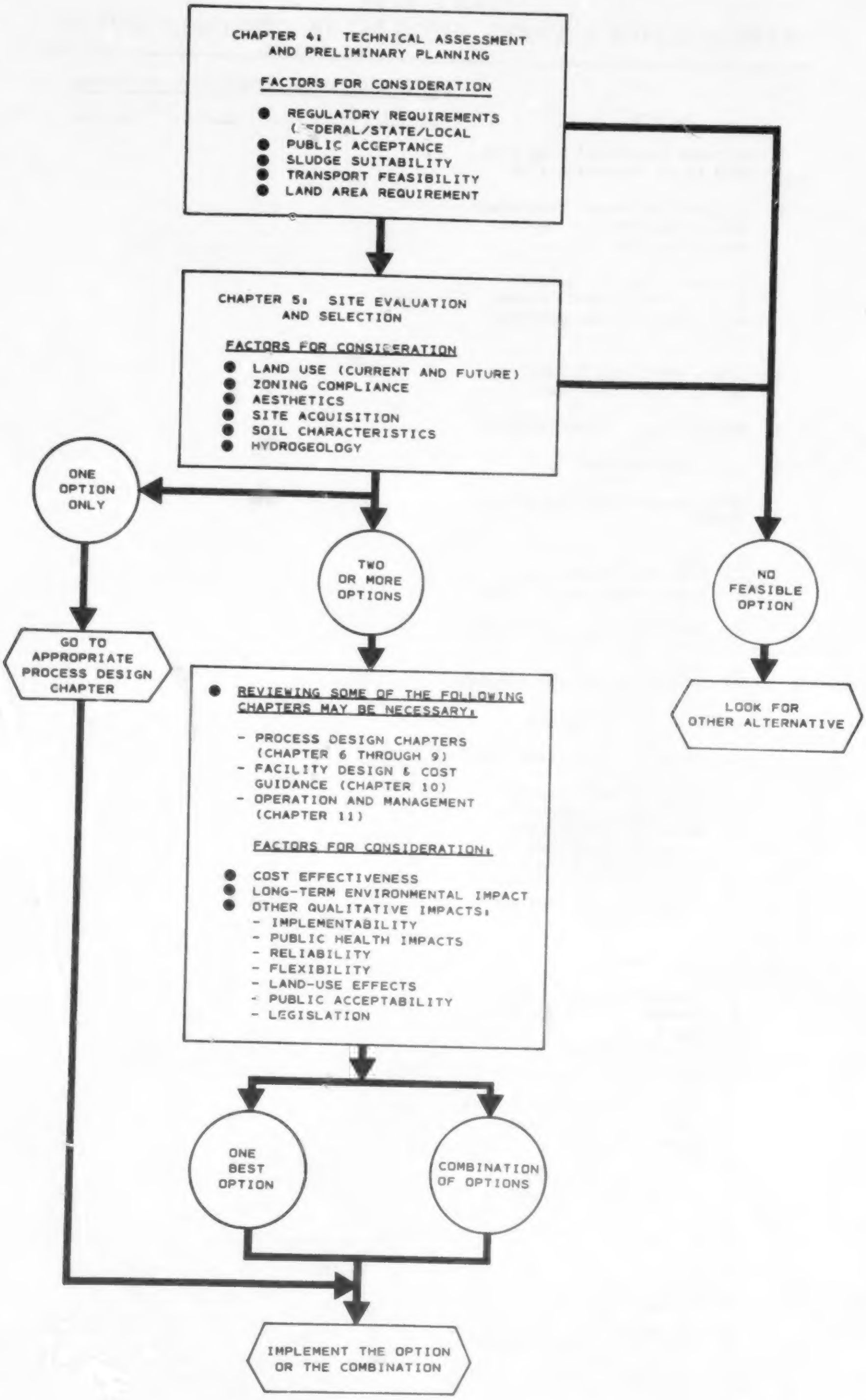
CHAPTER 4: TECHNICAL ASSESSMENT AND PRELIMINARY PLANNING
FACTORS FOR CONSIDERATION
REGULATORY REQUIREMENTS (FEDERAL/STATE/LOCAL
PUBLIC ACCEPTANCE
SLUDGE SUITABILITY
TRANSPORT FEASIBILITY
LAND AREA REQUIREMENT
CHAPTER 5: SITE EVALUATION AND SELECTION
FACTORS FOR CONSIDERATION
LAND USE (CURRENT AND FUTURE)
ZONING COMPLIANCE
AESTHETICS
SITE ACQUISITION
SOIL CHARACTERISTICS
HYDROGEOLOGY
ONE OPTION ONLY
TWO OR MORE OPTIONS
NO FEASIBLE OPTION
GO TO APPROPRIATE PROCESS DESIGN CHAPTER
LOOK FOR OTHER ALTERNATIVE
REVIEWING SOME OF THE FOLLOWING CHAPTERS MAY BE NECESSARY:
- PROCESS DESIGN CHAPTERS (CHAPTER 6 THROUGH 9)
- FACILITY DESIGN & COST GUIDANCE (CHAPTER 10)
- OPERATION AND MANAGEMENT (CHAPTER 11)
FACTORS FOR CONSIDERATION:
COST EFFECTIVENESS
LONG-TERM ENVIRONMENTAL IMPACT
OTHER QUALITATIVE IMPACTS:
- IMPLEMENTABILITY
- PUBLIC HEALTH IMPACTS
- RELIABILITY
- FLEXIBILITY
- LAND-USE EFFECTS
- PUBLIC ACCEPTABILITY
- LEGISLATION
ONE BEST OPTION
COMBINATION OF OPTIONS
IMPLEMENT THE OPTION OR THE COMBINATION

Figure 5-3. Planning, site selection, and option selection sequence.

TABLE 5-13
EXAMPLE DESIGN FEATURES CHECKLIST OF CANDIDATE OPTIONS

Subject	Candidate Option or Combination of Options			
	1.______	2.______	3.______	4.______
1. Distance and travel time from POTW to the candidate site				
2. Distance and travel time from the storage facility to the candidate site				
3. Distance from the nearest existing development, neighbors, etc., to the candidate site				
4. Sludge modification requirements, e.g., dewatering				
5. Mode of sludge transportation				
6. Land area required				
7. Site preparation/construction needs:				
a. None				
b. Clearing and grading				
c. Access roads (on-site and off-site)				
d. Buildings, e.g., equipment storage				
e. Fences				
f. Sludge storage and transfer facilities				
g. On-site drainage control structures				
h. Off-site runoff diversion structures				
i. On-site runoff storage				
j. Flood control structure				
k. Ground water pollution control structure, e.g., subsurface drain system				
l. Soil modification requirements, e.g., lime addition, etc.				
8. Equipment needs:				
a. Sludge transport vehicle				
b. Dredge				
c. Pumps				
d. Crawler tractor				
e. Subsurface injection unit				
f. Tillage tractor				
g. Sludge application vehicle				
h. Nurse tanks or tracks				
i. Road sweeper				
j. Washing trucks				
k. Irrigation equipment				
l. Appurtenant equipment				
9. Monitoring requirements:				
a. Soil				
b. Vegetation				
c. Surface water				
d. Ground water				
e. Leachate (unsaturated soil zone)				
f. Sludge analysis				
10. Operational needs				
a. Labor				
b. Management				
c. Energy				
d. Repair				

- Land use effects.
- Public acceptance.
- Legislation (local, state, and federal).

5.8.1 Qualitative Impact Comparison

The qualitative comparison of each land application option is based on the experience and judgement of the project planners and designers. This is more difficult than a cost comparison, because the level of each impact is more ambiguous and subject to differences of opinion. An example of a qualitative factor comparison for a hypothetical city is presented in Table 5-14. An example of a scoring system is presented in Section 4.4 of the Process Design Manual for Municipal Sludge Landfills (18). The scoring system should permit an "override" when dominating negative or positive factors exist.

5.9 Site Selection Example

Each of the process design chapters (Chapters 6 through 9) provides a detailed example of the design of a specific land application option. This section provides a brief example of the site selection procedure that could be used for a typical medium-sized community.

5.9.1 City Characteristics

- Population - 34,000.
- Wastewater volume - 0.18 m^3/s (4 M gal/day).
- Industrial wastewater contribution - approximately 10 percent.
- POTW description - conventional activated sludge, with primary and waste activated sludge treated by anaerobic digestion.

5.9.2 Sludge Characteristics

- Daily sludge generation - 2.36 dry mt/day (2.6 dry T/day).
- Average solids content - 4 percent.
- Average chemical properties (dry weight basis):
    - Total N - 3 percent.
    - NH_4-N - 1 percent.
    - Total P - 2 percent.
    - Total K - 0.5 percent.
    - Pb - 500 mg/kg.
    - Zn - 2,000 mg/kg.
    - Cu - 500 mg/kg.
    - Ni - 100 mg/kg.
    - Cd - 15 mg/kg.

TABLE 5-14
COMPARISON OF QUALITATIVE FACTORS FOR A HYPOTHETICAL PROJECT

Alternative Process/Option	Environmental Concerns	Reliability	Flexibility	Land Availability	Land Use Effects	Constraints	Remarks
Sludge dewatering	--	Good	High	High	Minor	Modification to treatment plant	High capital cost
Sludge truck transport	Traffic congestion, noise	Good	High	N/A	N/A	Accident liability	Consider private haulers
Sludge pipeline transport	Pipeline construction	High	Fair	Fair	Minor	Pipeline right of way	Only applicable for DLD site
Sludge storage at land application site(s)	Odors, ground water contamination	Fair	Good	Good	Detrimental	Odor control	Restrictions on distance to nearest residence or public use facility
Application of sludge to private cropland at low agronomic rates	Surface water pollution, soil metal accumulation, limits on food chain crops	Good	Fair	Good	Beneficial	Scheduling of application, requires large area	Good experience elsewhere, must deal with many landowners
Application of sludge to dedicated disposal site at high rates	Surface water pollution, ground water contamination, odors, noise, and dust; limits on future land use	High	High	High	Detrimental	Land purchase, obtaining regulatory approvals, odor control	Removes land from tax rolls, requires condemnation procedures
Application of sludge to forest land at low agronomic rates	Surface water pollution, public contact, aerosols	Fair	Fair	Fair	Beneficial	Obtaining regulatory approval, requires large area	No other similar projects in state, must deal with several landowners
Application of sludge to reclaim disturbed or marginal lands	Surface water pollution, ground water contamination limits on future land use	Good	Fair	Fair	Beneficial	Obtaining regulatory approval, requires large land area	Good expense in some locations, most deal with land owners

5.9.3 Regulations Considered

Assume that agricultural utilization is the only option being considered, and that special permits are not required for sludge application, provided that:

1. Annual sludge applications do not exceed either the nitrogen recommendations for the crop grown or the 2 kg Cd/ha (1.8 lb/ac) limitation specified by the state agency.
2. Soil is maintained at pH 6.5 or above.
3. Annual program for routine soil testing (N, P, K) and lime requirement (pH) is implemented.
4. Wastewater treatment plant measures the chemical composition of sludge.
5. Records are maintained on the location and the amount of sludge applied.

5.9.4 Public Acceptance

Assume that public acceptance of land application of sludge is judged to be very good. Several nearby communities have previously established agricultural utilization programs with excellent results. Sludge characteristics from these communities were similar as were their farm management and cropping patterns involving corn, soybeans, oats, wheat, and pastureland.

Several articles had appeared in the local newspaper indicating that escalating landfill costs were causing the city to study various disposal alternatives. No public opposition groups are known to exist.

5.9.5 Preliminary Feasibility Assessment

The above preliminary information was sufficiently encouraging to warrant further study of the agricultural use option.

5.9.6 Estimate Land Area Required

An application rate of 22.4 mt/ha/year (10 T/ac/year) was used as a first approximation (see Table 4-3). The acreage required for the city was estimated as follows:

$$\text{Acreage needed} = \frac{2.36 \text{ mt/day} \times 365 \text{ days/yr}}{22.4 \text{ t/ha/yr}} = 38.4 \text{ ha}$$

Thus, assume 40 ha (100 ac) for the preliminary search.

5.9.7 Eliminate Unsuitable Areas

Figure 5-4 shows a general area map containing the town and surrounding communities. Three concentric rings of 10, 20, and 30 km (6.2, 12.4, and 18.6 mi) were drawn around the POTW. Areas directly south of the POTW were immediately excluded because of the town boundaries. Similarly, areas east and southeast were excluded because of the town's projected growth pattern, the encroachment of a neighboring city, and the municipal airport. Further investigations to identify potential application sites were thus concentrated to the west and northwest.

5.9.8 Identify Suitable Areas

Soil maps obtained from the local SCS office were examined within the three radii. Areas within the 10-km (7-mi) ring were given first priority because of their proximity to the POTW. Sufficient land was located within this distance, and the areas contained within the second and third radii were not investigated.

Figure 5-5 is a general soil map showing one potential area available for sludge utilization. A detailed soil map of the area is shown in Figure 5-6, and the map legend is presented in Table 5-15.

Information presented in the soil survey report included: slope, drainage, depth to seasonal water table, and depth to bedrock. Cation exchange capacities were estimated from texture, and a ranking was developed to estimate soil suitability for sludge application. The preferred candidate sites were further examined for the characteristics listed in Table 5-13. The rankings developed in Table 5-15 are explained in the footnotes to the table.

Since the detailed soil map was based on an aerial photo, farm buildings, houses, etc., were usually identifiable. Certain portions within this area were excluded, including:

- Areas in close proximity to houses, schools, and other inhabited buildings.

- Areas immediately adjacent to ponds, lakes, rivers, and streams.

Those areas were shaded (Figure 5-6), using a mylar overlay. The remaining unshaded areas, covering about 930 ha (2,300 ac), were generally pastureland with some fields of corn and oats. Within this area is about 175 ha (432 ac) which ranks in Category 1 in Table 5-15.

The land in the site area was owned by three individuals. Since the 175 ha (432 ac) was far in excess of the 40 ha (100 ac) required, no further sites were investigated.

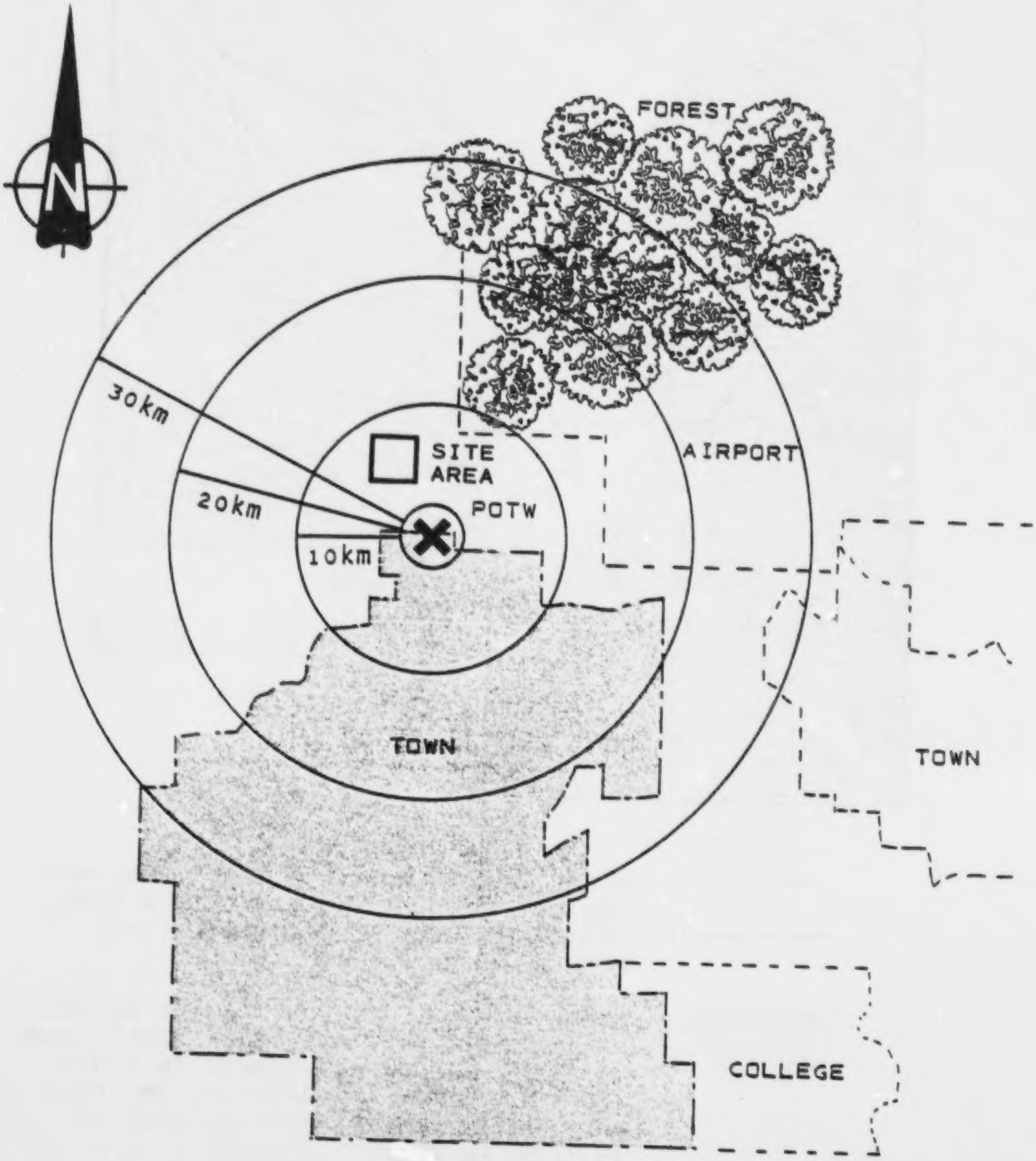

Figure 5-4. General area map with concentric rings.

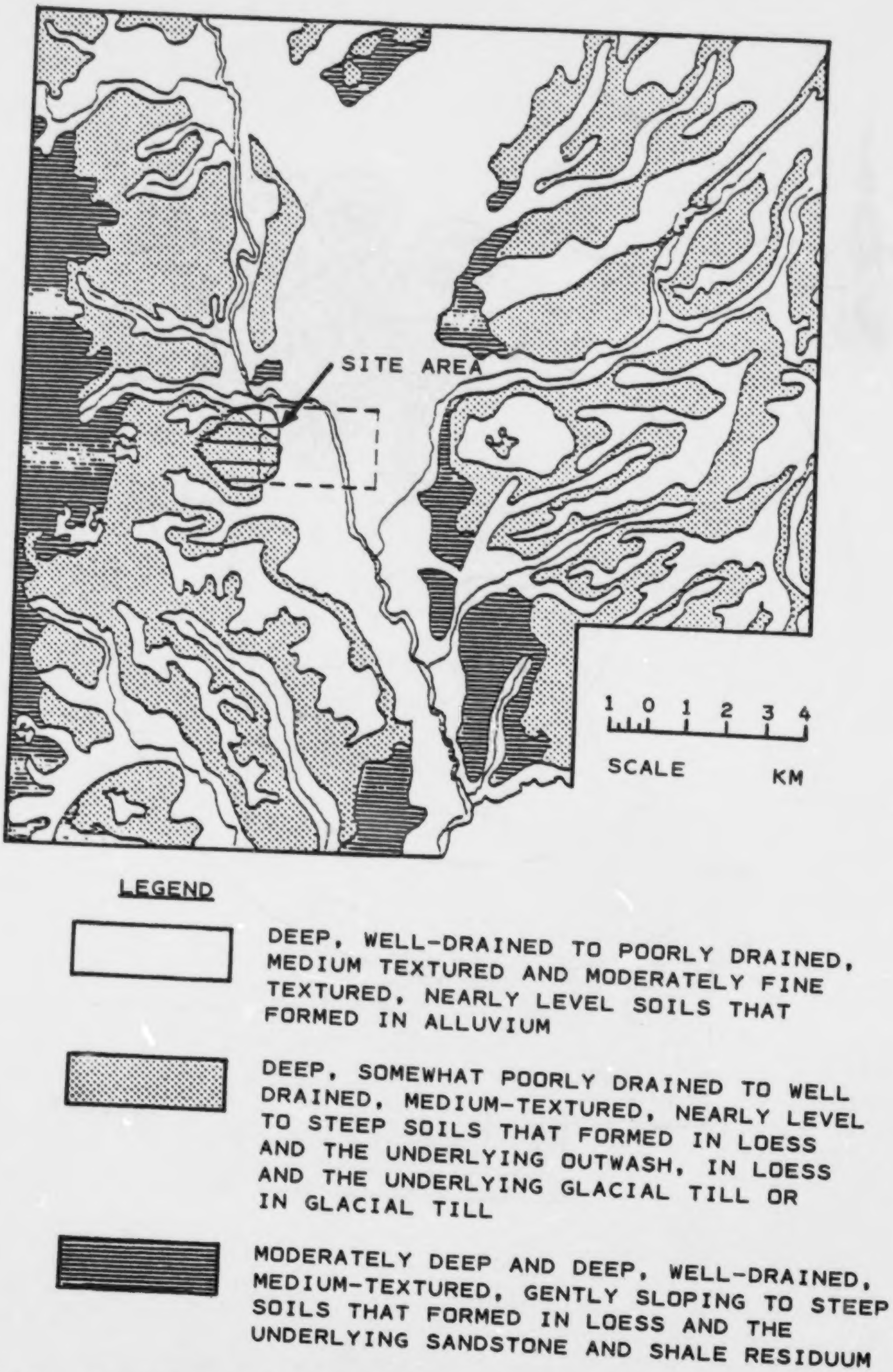
SITE AREA
1 0 1 2 3 4
SCALE KM
LEGEND
DEEP, WELL-DRAINED TO POORLY DRAINED, MEDIUM TEXTURED AND MODERATELY FINE TEXTURED, NEARLY LEVEL SOILS THAT FORMED IN ALLUVIUM
DEEP, SOMEWHAT POORLY DRAINED TO WELL DRAINED, MEDIUM-TEXTURED, NEARLY LEVEL TO STEEP SOILS THAT FORMED IN LOESS AND THE UNDERLYING OUTWASH, IN LOESS AND THE UNDERLYING GLACIAL TILL OR IN GLACIAL TILL
MODERATELY DEEP AND DEEP, WELL-DRAINED, MEDIUM-TEXTURED, GENTLY SLOPING TO STEEP SOILS THAT FORMED IN LOESS AND THE UNDERLYING SANDSTONE AND SHALE RESIDUUM

Figure 5-5. General soil map showing area selected for sludge utilization.

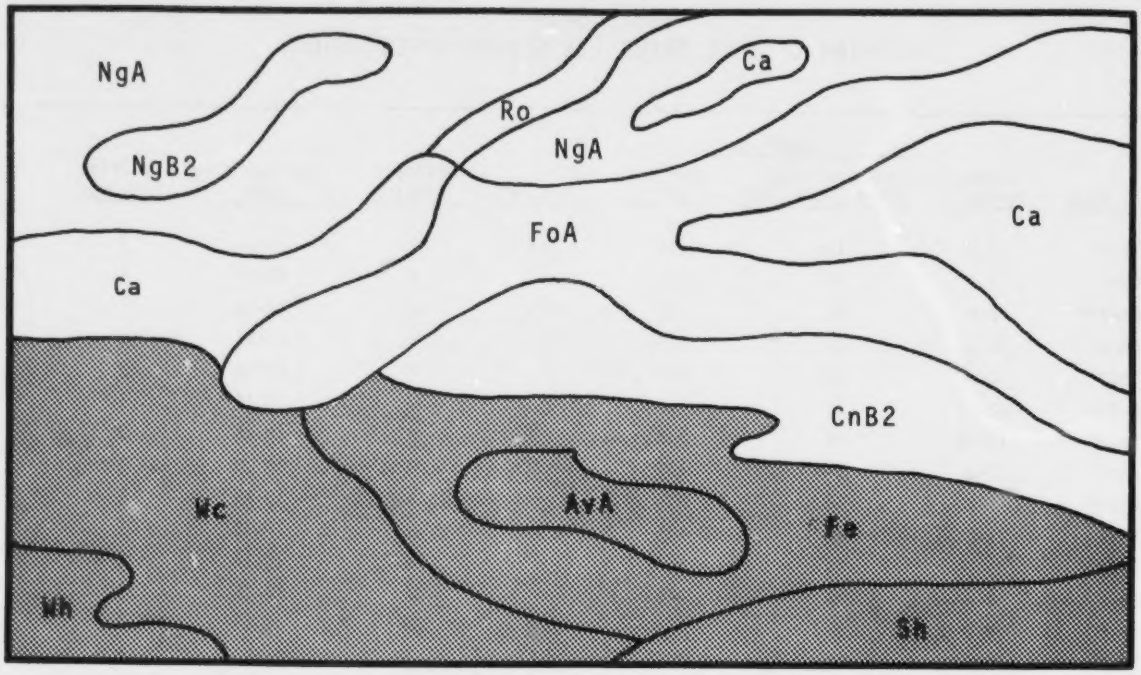

Figure 5-6. Detailed soil survey map of potential site for sludge application. Areas not suitable for use are shaded. See Table 5-15 for ranking of soil types.

TABLE 5-15
RANKING OF SOIL TYPES FOR SLUDGE APPLICATION

Soil Type	Slope Percent	Depth to Seasonal High Water Table (ft)	Depth to Bedrock (ft)	Texture*	Drainage Class†	Approximate CEC	Relative Ranking#
AvA**	0-2	1-3	>15	sil	P	10-15	3
Ca**	0.2	>6	>15	sil	W	10-15	1
CnB2**	2-6	>6	>15	sil	W	10-15	1
CnC2	6-12	>6	>15	sil	W	10-15	2
CnC3	6-12	>6	>15	sil	W	10-15	2
CnD2	12-18	>6	>15	sil	W	10-15	3
CnD3	12-18	>6	>15	sil	W	10-15	3
Fe**	0-2	3-6	>15	sil	W	10-15	2
FoA**	0-2	>6	>15	l	W	10-15	1
FoB2	2-4	>6	>15	l	W	10-15	1
FoC3	6-12	>6	>15	l	W	10-15	2
Ge	0-2	>6	>15	l	W	10-15	1
Hh	0-2	1-3	>10	sil	SP	10-15	3
La	0-2	>6	>15	gsal	W	>5	1
MbA	0-2	>6	>15	l	W	10-15	1
MbB2	2-6	>6	>15	l	W	10-15	1
Md	0-2	3-6	>15	sicl	MW	>15	2
NgA**	0-2	>6	>15	l	W	10-15	1
NgB2**	2-6	>6	>15	l	W	10-15	1
NnA	0-2	>6	>15	l	W	10-15	1
RnF	0-2	>6	>15	gl	E	>5	1
Ro**	0-2	>6	>15	sicl	W	>15	1
Rp	0-2	>6	>15	sicl	W	>15	1
RsB2	2-6	3-6	>15	sil	MW	10-15	2
Sc	0-2	0-1	>15	sicl	VP	>15	3
Sh**	0-2	1-3	>15	sil	SP	10-15	3
Sm	0-2	1-3	>15	l	SP	10-15	3
Sz	0-2	>6	>15	sal	W	5-10	1
Wc**	0-2	0-1	>15	cl	VP	>15	3
Wh**	0-2	1-3	>15	l	SP	10-15	3

* l, loam; gsal, gravelly sandy loam; sil, silt, loam; sicl, silty clay loam; cl, clay loam; sal, sandy loam; gl, gravelly loam.

† E, excessively drained; W, well drained; MW, moderately well drained; SP, somewhat poorly drained; P, poorly drained; VP, very poorly drained.

# 1, 0-6 percent slope, >6 ft to water table and >15 to bedrock. 2, 6-12 percent slope or 3-6 ft to water table. 3, 12-18 percent slope or 0-3 ft to water table.

** Soil types present on potential site (see Figure 5-6).

Soils present in the area were generally silt loams, having a CEC of approximately 10 meq/100 g. Representative soil analysis was as follows:

- CEC - 10 meq/100 g.
- Soil pH - 6.0 (1:1 with water).
- Available P - 16.8 kg/ha (15 lb/ac).
- Available K - 84 kg/ha (75 lb/ac).
- Lime necessary to raise pH to 6.5 - 5.4 t/ha (2.4 T/ac).

The three landowners were contacted individually to determine their willingness to participate. All expressed considerable interest in participating in the program.

5.9.9 Site Survey and Field Investigation

These efforts confirmed the suitability of the site selected. Agreements were thus made with each landowner to accept municipal sludge.

5.9.10 Cost Analysis

No land costs were incurred since the landowners agreed to accept the sludge. Capital costs included: transportation vehicle, application vehicle, sludge-loading apparatus with pumps, pipes, concrete pad, electrical controls, and storage facilities. Annual costs for this option were estimated to be \$73/dry mt (\$66/dry T) as compared to \$85/dry mt (\$77/dry T) for landfilling the sludge at a site 25 km (15.5 m) from the POTW.

5.9.11 Final Site Selection

The 175 ha (432 ac) of best quality land were distributed over seven individual fields, several of which were not serviced by all-weather roads. These fields would only be used if complicating factors (e.g., field or crop conditions) rendered the other fields unusable. The contractual agreement with the three individuals specified that sludges would be applied to certain fields (to be determined at owner discretion) at rates commensurate with crop nitrogen requirements, and to prevent any adverse long-term effects of heavy metal accumulations.

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CHAPTER 6

PROCESS DESIGN FOR AGRICULTURAL UTILIZATION

6.1 General

The purpose of this chapter is to present detailed design information for the utilization of sewage sludge on agricultural cropland. The design example presented at the end of this chapter assumes that (1) the agricultural utilization option has been selected; (2) preliminary planning has been completed; and (3) a transportation system has been chosen to convey sludge to the application site. Primary emphasis will be placed on growing crops such as corn, soybeans, small grains, cotton, sorghum, and forages.

The design approach presented in this chapter is based on the utilization of sludge as a low-analysis replacement for commercial fertilizers. The application rate of sludge is typically designed for either the N or P needs of the crop grown on a particular soil. In addition, the sludge application rate must be consistent with existing federal, state, and local regulations relative to pathogens, metals, or organics contained in the sludge.

The U.S. EPA promulgated interim final regulations in 1979 for states to use in limiting the total amount of Cd that can be applied to cropland each year as well as over a period of years (10). Many states have also developed regulations or guidelines concerning annual N and Cd limits and cumulative Cd limits applied to agricultural cropland. If sludge is applied to cropland at rates greater than the limits established for N, increased monitoring will usually be required for potential nitrate movement into drinking water aquifers. Exceeding the allowable limits for Cd applications may result in restrictions on crop use (i.e., crop use only for animal feed), and possibly restrictions on future land use.

The goal of the basic design approach presented in this chapter is to optimize crop yields generally on privately owned land through applications of both sludge and supplemental fertilizers, if needed. However, other agricultural use options involving sludge application at rates in excess of crop use rates are possible on both private and municipally owned land. The information contained in Reference (10) will be referred to as the "Criteria" in this chapter. These regulations are based on a management rather than a performance approach to minimizing potential problems associated with applying sludge on cropland. The "Criteria" (10) primarily address pathogens, Cd, and PCB's contained in sludges. Prior to designing a specific system, pertinent current state and local regulations must be obtained. In addition, federal regulations should be examined to determine if they have been changed since the publication of this manual.

The design example presented at the end of this chapter assumes that basic sludge and crop information has been collected. The sludge composition data required to ensure good design include:

- Total solids.
- Total N.
- NH_4-N.
- NO_3-N.
- Total P.
- Total K.
- Total PCB's.
- Total Pb.
- Total Zn.
- Total Cu.
- Total Ni.
- Total Cd.

Other concerns include the possibility of odors or potential exposure to pathogens due to inadequate sludge treatment or poor site management. The design approach described in this chapter assumes that the sludge has been properly stabilized to reduce pathogens and odor potential. Objections by rural residents to landspreading might be encountered if they perceive a situation in which the urban community imposes its waste disposal problem on the rural community. A large city is more likely to be seen as an outsider than a small city. Rural acceptance will be more readily forthcoming if local autonomy is assured, and if the project has the apparent flexibility to incorporate needed changes.

The initial task for obtaining public support (see Chapter 3) begins with the selection of a project team whose members can offer technical service and expertise. Suggested personnel include:

- Representatives of the city engineering or public works department to direct the project and coordinate team activities.

- The POTW superintendent or consultant knowledgeable in treatment plant operations; preferably, a permanent sludge management person whom the public knows as the person to contact.

- Local SCS agent and agricultural extension service representatives to advise on site selection, management, soil and vegetation evaluation, and other matters.

- Local farm management firm.

Information must also be available on the types of crops to be grown, attainable yield level, and the relationship between soil tests and fertilizer application rates.

6.2 Detailed Site Investigations

An advantage of the agronomic utilization option is the minimization of detailed site investigations. The design approach emphasizes use of sludge as a low-analysis fertilizer with the application rates being constrained by the N requirements or P requirements (as in Ohio) of the crop grown and by the accumulation of metals in the surface soil. The necessary information on general site characteristics can be obtained from a combination of soil survey maps and site visits. The principal soil chemical analyses required are soil tests which are routinely conducted to develop recommendations for application of conventional fertilizer materials. Additional information on site evaluation and selection can be found in Chapter 5.

6.2.1 General Soil Properties

Following the selection of general areas, soil survey maps or equivalent information can be used to delineate the specific locations that could be used for sludge application. Chapter 5 describes the screening and selection procedures to be used.

6.2.1.1 Physical Features

Several states have established guidelines or regulations for minimum distances between an area receiving sludge and adjacent site features such as residential developments, inhabitated dwellings, ponds and lakes, springs, 10-year high water mark of streams, rivers and creeks, water supply wells, and public road rights-of-way. The potential for surface runoff of liquid sludge is the primary reason for these guidelines. If liquid sludge is immediately incorporated into the soil rather than allowed to remain on the soil surface, it can then be applied at a closer distance. Since the potential for runoff is significantly less for dewatered sludge than for liquid sludge, the setback distances for dewatered sludge applied to the soil surface are generally the same as those for liquid sludge incorporated into the soil. In addition, very low sludge application rates, e.g., less than 2-4 mt/ha (1-2 T/ac), reduce the risks of runoff, and may allow reduction of setback distances. General guidelines for setback distances from sites treated with liquid and dewatered sludges by surface or incorporated applications are presented in Chapter 5, Table 5-7. Local and/or state regulations must be consulted when designing a specific project, since the criteria in Table 5-7 may not be as stringent as particular local limits.

6.2.1.2 Topography

The sludge application rates employed in an agricultural utilization program typically range from 5 to 20 mt/ha (2.2 to 9 T/ac) on a dry weight basis. For liquid sludge at 5 percent solids, these rates correspond to 100 to 400 m^3/ha (0.4 to 1.5 acre-in). The volumes of liquid sludge applied are therefore far less than the natural annual rainfall in nearly all regions of the United States. Since these volumes are not excessive, use of appropriate sludge application techniques and runoff control measures for different soil slopes will minimize the potential for contamination of surface waters. General slope criteria are presented in, Chapter 5, Table 5-2, for preliminary site selection purposes.

The measures used to control surface runoff from soils treated with sludge are the same as those designed to prevent soil erosion. These practices include strip cropping, terraces, grassed waterways, and reduced tillage systems (e.g., chisel plowing, no-till planting). The presence of vegetation and/or crop residues on the soil surface is effective in reducing runoff from steeply sloping soils. For many cropping systems (e.g., corn, soybeans, small grains), liquid sludge applied to the surface is incorporated into the soil by plowing or disking prior to crop planting, further reducing the potential for loss of sludge constituents via surface runoff. In essence, selection of the proper sludge application method (surface or incorporation) in conjunction with currently recommended practices for control of soil erosion will essentially eliminate the potential contamination of surface waters or adjacent lands by sludge constituents.

6.2.1.3 Depth to Ground Water

The ideal sludge application site would contain a deep and well-developed soil to protect the integrity of ground water resources. A basic philosophy inherent in federal and many state regulations is to design sludge application systems that are based on sound agronomic principles, so that sludge utilization poses no greater threat to ground water resources than current agricultural practices. Because the ground water fluctuates on a seasonal basis in many soils, difficulties are encountered in establishing an acceptable minimum depth to ground water for sludge application sites. Usually, the greater the depth of soil above ground water, the less potential for sludge constituents (primarily NO_3^-) to migrate into water supplies. Local or state regulations often specify that the minimum distance to ground water should be 1 m (3 ft). However, this type of regulation is often difficult to interpret in practice, because many productive agricultural soils have naturally occurring seasonal water tables within 1 m (3 ft) of the surface. These soils can be ideal sites for sludge application, because tile drains have been installed to improve subsurface drainage, and because the soils have the fertility to support excellent crop yields. The perched water table beneath these soils is normally not used as a water supply. (See Table 5-6 for general guidance on depth to ground water.)

The primary sludge constituent that can leach into ground water is nitrate nitrogen. Following application of sludge, nitrate is formed by nitrification of the ammonium either added in the sludge or released during decomposition of sludge organic N. Nitrate is a water-soluble anion that will move downward readily in the soil profile. Nitrate leaching will occur if excessive amounts of N are supplied to soils in the form of fertilizers, animal wastes, sludges, or other materials. Nitrate leaching is minimized by applying sludge at a rate and time consistent with the N required by the crop grown. Downward movement of metals, phosphorus, and organics are usually not encountered, because these sludge constituents are relatively immobile in soils. Essentially all of the applied metals, pathogens, phosphorus, and organics remain in the upper 15 to 30 cm (5 to 10 in) of soil (i.e., depth of tillage).

The movement of metals is further reduced by maintaining the soil at pH 6.5 or above, as currently required to minimize plant uptake of metals.

6.2.2 Soil Sampling and Analysis

A soil sampling and analysis program is needed to establish limits for cumulative metal applications, to determine the amounts of supplemental fertilizer needed, and to evaluate soil pH. These data, in conjunction with crop and sludge data, will allow calculations of annual sludge application rates and site life. It is recommended that soil samples be collected from each field that will be treated with sludge. If a given field exceeds 10 ha (25 ac), individual soil samples should be collected from each soil series within the field. Valid soil sampling procedures are essential. Information can be obtained from university or private soil testing laboratories on proper procedures for obtaining and handling soil samples (also see Appendix C). The required soil analysis determines (1) plant available P and K; (2) soil pH and lime requirement; and (3) CEC. Sampling and analytical methods are presented in Appendix C. These tests, except for CEC, are routinely performed for most farmers every 2 to 4 years.

In many regions of the United States, a specific soil test is not used to develop N fertilizer needs. Some midwestern states relate N fertilizer applications to soil organic matter, while the nitrate contained in the soil profile is considered in some western states where crops are grown under irrigation. Information presented in this chapter assumes that N application rates are based on the N required by a crop at a specific yield level.

6.2.2.1 Plant Available Phosphorus and Potassium

The amount of plant available P is determined by analyzing the amount of P removed from soil by a particular extractant. The extractant used varies in different regions of the United States, but is typically a dilute acid or a bicarbonate solution. Essentially, all P taken up by crops is present in insoluble forms in soils rather than being in the soil solution. In all states, it has been determined that there is a relationship between the amount of extractable P in a soil and the amount of P fertilizer needed for various yields of different crops. Such information can be obtained from extension services, universities, etc.

As with P, an extractant is used to determine the plant available K in a soil. Potassium available for plant uptake is present in the soil solution, and is also retained as an exchangeable cation on the cation exchange complex of the soil. The amount of plant available K is then used to determine the K fertilizer rate for the crop grown. Sludges are usually deficient in K, relative to crop needs.

These test data are then used to calculate whether supplemental P or K fertilizer is needed to optimize crop yields following sludge application. Assistance on interpreting soil test data and fertilizer recommendations can be obtained from local extension agents, farm management and consultant firms, and fertilizer dealers.

6.2.2.2 Soil pH and Lime Requirement

Most states require that soils treated with sludge be maintained at pH 6.5 or above to minimize the uptake of metals by crops. Soil pH is routinely determined by soil testing laboratories. If soil pH is less than 6.5, a laboratory test procedure is used to estimate the amount of agricultural limestone required to adjust the soil to pH 6.5.

Soil pH control has been practiced routinely in those areas of the United States where leguminous crops (e.g., clover, alfalfa, peas, beans) are grown. Fortunately, limestone deposits are normally abundant in these regions, resulting in minimal costs associated with liming soils to pH 6.5. However, considerable cost may be associated with liming soils to pH 6.5 in other areas of the United States (e.g., eastern and southeastern states). Soils in these regions tend to be naturally acid, and may require relatively large amounts of limestone (12 to 20 mt/ha; 5 to 8 T/ac) to attain pH 6.5. Furthermore, the general trend toward increased growth of cash grain crops (corn, small grains) has caused soil pH to decrease because of greater N fertilizer use. Excellent yields of corn, soybeans, and wheat can be obtained at a soil pH of 5.5 to 6.0. Most soils in the western United States contain free calcium carbonate, and naturally possess a pH >6.5.

Soil pH is buffered by inorganic and organic colloids. Thus, it does not increase immediately after limestone applications, nor does it decrease soon after sludge or N fertilizer additions. It is strongly recommended that soil pH be maintained at 6.5 or above after sludge applications cease to minimize plant uptake of metals. All calcareous soils naturally meet this recommendation.

6.2.2.3 Cation Exchange Capacity

Many states have established limitations on the total (cumulative) amounts of Pb, Zn, Cu, Ni, and Cd that can be applied to cropland. These limits then control the total amount of sludge that can be applied over a period of years (see Section 6.3.5). Soil CEC is employed to relate total metal additions to the ability of a soil to minimize metal uptake by plants. The CEC of a soil is a measure of the net negative charge associated with both clay minerals and organic matter. The CEC determination is a routine analysis in many soil testing laboratories, and will be done upon request in nearly all other laboratories.

6.3 Constraints

The constraints associated with application of sludge on agricultural cropland are dependent on the type of crop grown, soil characteristics, and specific sludge constituents, including pathogens, organics, N, Pb, Zn, Cu, Ni, and Cd. Since state regulations vary in different regions of the United States, the following discussion emphasizes the general constraints placed on the application of sludge on cropland by the "Criteria" (10).

6.3.1 Pathogens

Untreated raw sludges contain a variety of potential pathogens, including bacteria, protozoa, helminthic parasites, and viruses. Additional information on the pathogen content of sludges and their fate in soils is contained in Appendix A. Sludge treatment processes can be used to significantly reduce the pathogen content of sludges. Typical stabilization processes include aerobic digestion, anaerobic digestion, long-term storage in a lagoon, extended air-drying on drying beds, composting, and lime (CaO) treatment. The "Criteria" (10) refer to these processes as ones that "significantly reduce pathogens." All sludges applied to agricultural cropland must be treated by such a process, if a crop that enters the human diet, either directly or indirectly, is grown. An example of direct entry into the human diet would be bread derived from wheat grown in sludge-treated soils. Corn or forage fed to livestock would constitute a route for indirect entry. The "Criteria" (10) also contain other stipulations on sludge application to cropland: (1) site access must be controlled for 12 months after application; (2) no animals should be grazed on the site for 1 month after application if the animal product will be consumed by humans; and (3) crops consumed raw (e.g., root crops and vegetables) by humans cannot be grown for 18 months after the time of sludge application, unless there is no contact between crop and sludge (e.g., peas or corn which are not typically consumed raw).

The "Criteria" (10) also define conditions for sludge treatment processes that "further reduce pathogen content of sludge." Examples of these processes would be high-temperature aerobic or anaerobic digestion, irradiation, and heat drying. If one of these processes is used to further reduce the pathogen content of sludge, crops consumed raw can be grown within 18 months after application. The pertinent federal regulations, along with state or local rules, must be consulted to design a specific system.

There have not been any serious disease problems reported from the application of stabilized sludges on agricultural cropland. Numerous concerns are always voiced by the public whenever sludge utilization projects are discussed at public hearings. The emotional arguments presented are always difficult to counteract, because the imagined problems and aesthetic considerations (i.e., growing food for human consumption on soils treated with human wastes) are not negated by merely presenting facts. In general, the public wants a guarantee that not a single virus or bacteria will ever enter their food or water supply. Such a guarantee cannot be made for any type of wastewater treatment or sludge management program.

6.3.2 Nitrogen

Nitrogen is the nutrient that is required in the largest amounts by all crops. The addition of N to soils in excess of crop needs results in the potential for NO_3^- contamination of ground water. Nitrate is not adsorbed by soil particles, and will readily move downward as water percolates through the soil profile. The ammonium-N either initially present or released from organic N will be rapidly converted to NO_3^- following addition of sludge to soil. A similar problem results from excessive applications of animal wastes and conventional nitrogen fertilizer materials.

High NO_3^- levels in water supplies may result in health problems for both infants and livestock. The maximum allowable concentration of NO_3^- in potable drinking water has been established at 10 mg NO_3^--N/l (45 mg NO_3/l). The amount of plant available N applied to soils in sewage sludge should be consistent with the current N fertilizer recommendations for the crop grown. As a result, the threat of NO_3 contamination of ground water at a well managed sludge utilization site should be no greater than that caused by the use of conventional N fertilizers. This approach places a constraint on the amount of sludge applied to soil each year, because N requirements of different crops can range from 50 kg N/ha (45 lb N/ac) to over 350 kg N/ha (312 lb N/ac).

6.3.3 Organics

Most sludges contain organic compounds, primarily chlorinated hydrocarbons, which are relatively resistant to decomposition in soils and may be of concern from a human health standpoint. PCB's are the only group of organic compounds addressed in the "Criteria" (10).

These federal regulations require that all sludges containing greater than 10 mg PCB/kg must be incorporated into the soil whenever animal feed crops are grown. The principal problem arising from PCB's is direct ingestion by animals grazing on forages treated with surface-applied sludge. Dairy cattle are most susceptible to PCB contamination of forages, because PCB's in the diet are readily partitioned into milk fat. Several studies have shown that essentially no plant uptake of PCB's occurs, although PCB's can be adsorbed onto the surface of root crops such as carrots.

The majority of sludges in the United States contain less than 10 mg PCB/kg; therefore, PCB restrictions will limit the use of only a small percentage of sludges. Since PCB's are no longer manufactured, PCB-related constraints should become less common in the future. Other organic compounds detected in sludges are summarized in Appendix A.

6.3.4 Cadmium

From a human health standpoint, Cd is the sludge-borne metal that has received the greatest attention. It has been estimated that the current dietary intake of Cd by the U.S. population is less than 50 percent of the limit set by the World Health Organization, and that increased Cd levels are sometimes observed following application of sludges to soils. Cd contained in the diet, whether derived from soil or sludge sources, accumulates in the kidneys, and may cause a chronic disease called proteinuria (increased excretion of protein in the urine).

It is difficult to predict the effect of sludge application on Cd in the human diet for the following reasons:

- Crops vary markedly in Cd uptake (e.g., leafy vegetables are significantly higher in Cd than cereal crops).
- Cd uptake by crops is dependent on soil properties and the amount of Cd applied.
- The Cd content of the current human diet is not accurately known, and varies with each individual's diet preferences.
- Projected increases in dietary Cd due to sludge utilization are strongly influenced by the proportion of land treated with sludge, the types of crops grown, soil properties, and other factors.

The reader is referred to recent publications discussing the uptake of Cd by crops (14) and the impact of sludge application on dietary Cd (15). Table 6-1 summarizes relative accumulation of Cd in common food crops.

The "Criteria" (10) specify interim final limits for annual and cumulative amounts of Cd applied to different crops, and require that soil pH be maintained at 6.5 or above. These regulations were developed from considerations of allowable increases in dietary Cd for a worst case situation, e.g., a vegetarian growing 100 percent of his food on an acid, sludge-treated soil. Even though application of most sludges will increase the Cd content of some crops, the regulations were designed to limit the increases to a level where no adverse effect on human health would result. The crop Cd concentrations of concern to human health are far below those where Cd decreases crop yields (i.e., phytotoxicity from Cd), so phytotoxicity does not offer protection against excessive levels of Cd in crops. Some states have adopted more conservative limitations on total Cd applications to cropland, so it is imperative to consult state regulations when designing a specific system.

6.3.5 Lead, Zinc, Copper, and Nickel

In addition to Cd, the cumulative amounts of Pb, Zn, Cu, and Ni applied to soils in sludge can be used to determine the number of years that sludge can be utilized. The recommendations in Table 6-2 for Pb, Zn, Cu, and Ni were developed through the joint efforts of researchers in various Agricultural Experiment Stations, U. S. Department of Agriculture, and EPA, and were adopted as guidelines by EPA in 1977 (6). Some states have developed regulations which are very similar.

Limitations on total metal additions to soils are needed to protect soil productivity and animal health. The majority of crops do not accumulate Pb, but there is concern regarding the potential ingestion of Pb and possibly other trace elements (Cu, Se, Mo) by animals grazing on sludge-contaminated forages and indirect consumption of soil. The surface application of sludge on forages can lead to some sludge adhering to the foliage, resulting in direct consumption by grazing animals. Furthermore, raindrop splash can cause contamination of foliage with soil-sludge materials, and animals typically consume some soil when grazing. The total amounts of Zn, Cu, and Ni applied are limited, because crop yields will decrease (phytotoxicity) if excessive amounts of these metals are added to soils. In general, Zn, Cu, and Ni will be toxic to crops before their concentration in plant tissues reaches a level that poses a problem to human or animal health. The cumulative metal limits (Table 6-2) assume that soil pH is maintained at 6.5 or above during and after sludge application.

These cumulative metal limits are a function of soil CEC. The use of soil CEC in establishing metal limits does not imply that metals added to soils in sludge are retained by the exchange complex as an exchangeable cation. It has been shown experimentally that nearly all metals in sludge-amended soils are not present as an exchangeable cation (i.e., exchangeable with a neutral salt). Thus, CEC was chosen as an indicator of soil properties, since it is easily measured and related to soil components that minimize plant availability of sludge-borne metals in soil. In general, the CEC categories of <5, 5-15, and >15 meq/100 g correspond to sands, sandy loams, and silt loams, respectively; however, regional differences in this relationship occur.

Sludge applications should cease when any single metal limit is attained (see Table 6-2). If soil pH is maintained at 6.5 or above, cessation of sludge application at the limits presented should enable the growth of any crop in the future without adverse affects on yield. In addition, soil productivity will be at a level equal to, and most likely greater than, that which existed prior to initiation of sludge application.

6.3.6 Other Sludge Constituents

The yields of agronomic crops can be influenced by other sludge constituents in certain regions of the United States. For example, in arid regions where most crops are irrigated, soluble salts, Mo, and B should

TABLE 6-1
RELATIVE ACCUMULATION OF CADMIUM INTO EDIBLE PLANT PARTS BY DIFFERENT CROPS (7)*

High Uptake	Moderate Uptake	Low Uptake	Very Low Uptake
Lettuce	Kale	Cabbage	Snapbean family
Spinach	Collards	Sweet corn	Pea
Chard	Beet	Broccoli	Melon family
Escarole	Turnip root	Cauliflower	Tomato
Endive	Raddish globes	Brussel sprouts	Pepper
Cress	Mustard	Celery	Eggplant
Turnip greens	Potato	Berry fruits	Tree fruits
Beet greens	Onion		
Carrot			

* The above classification is based upon the response of crops grown on acidic soils that have received a cumulative Cd application of 5 kg/ha. It should not be implied that the above higher uptake crops cannot be grown on such a soil, or soils of higher Cd concentrations. Such crops can be safely grown if the soil pH is 6.5 or greater at the time of planting, since the tendency of the crop to accumulate heavy metals is significantly reduced as the soil pH increases above 6.5.

TABLE 6-2
RECOMMENDED CUMULATIVE LIMITS FOR METALS OF MAJOR CONCERN APPLIED TO AGRICULTURAL CROPLAND (6)(9)*

	Soil Cation Exchange Capacity, meq/100 g†,#		
	<5	5 to 15	>15
Metal	----------kg/ha (lb/ac)**----------		
Pb	560 (500)	1,120 (1,000)	2,240 (2,000)
Zn	280 (250)	560 (500)	1,120 (1,000)
Cu	140 (125)	280 (250)	560 (500)
Ni	140 (125)	280 (250)	560 (500)
Cd	5 (4.4)	10 (8.9)	20 (17.8)

* See Table 4-2 in Chapter 4 for guidance on use of sludge for production of fruits and vegetables.

† Interpolation should be used to obtain values in the CEC range 5-15.

# Soil must be maintained at pH 6.5 or above.

** lb/ac shown in parentheses.

be considered when determining sludge application rates. The concentration of these components in the irrigation water, along with the amount applied in sludge, should be considered to minimize any potential problems. Information on the quality of local irrigation water and the prevailing irrigation management systems must be obtained to design sludge utilization systems in irrigated regions (16). In nonirrigated areas, soluble salts are rarely a problem because of minimal soluble salts in sludge and low application rates.

Sludges may also contain other trace elements such as Hg, Cr, As, and Se. These elements are not included in the design criteria either because of the minimal uptake by crops (4)(6)(8) or the relatively low concentrations in most sludges. The range and median concentrations for elements commonly found in sludge are shown in Appendix A. Abnormally high levels of specific chemical species should be dealt with on a case-by-case basis. Pretreatment of industrial waste streams prior to discharge into the sewerage system may be necessary prior to utilization of sludge on cropland. Further, sludges that are grossly contaminated with metals or organics will not likely pass the U.S. EPA extraction procedure for toxic and hazardous waste (17), and must thus be disposed of at an approved hazardous waste disposal site.

6.4 Sludge Application Rate Calculations

Sludge application rates are calculated from data on sludge composition, soil test information, N fertilizer need of the crop grown, and limits on annual Cd additions. In essence, this approach views sludge as a substitute for conventional N fertilizers in crop production. The number of years that sludge can be applied is based on recommended limits for total additions of Pb, Zn, Cu, Ni, and Cd, as shown in Table 6-2.

Since the majority of sludges contain roughly equal amounts of total N and P while crops requirements for N are two to five times greater than those for P, a conservative approach to annual sludge application rates involves applying sludge to meet the P rather than N needs of the crop. Sludges could also be applied to agricultural cropland at rates that exceed the N requirements of crop or the prevailing limitations on Cd additions. These types of systems should be viewed as dedicated sludge disposal sites that require more intensive monitoring, careful control of the end use of any crop grown, and possible restrictions on future site use (see Chapter 9).

The general approach for determining application rates on agricultural cropland can be summarized as follows:

- Nutrient requirements for the crop selected are based on the yield level and soil test data. If sludge has been applied in previous years, fertilizer recommendations are corrected for carry-over of nutrients added by previous sludge additions.

- Annual sludge application rates are calculated based on N crop needs, Cd limitation, P crop needs, and fixed rate (may exceed N needed by crop or Cd limit).
- Supplemental fertilizer is determined from N, P, and K needed by crop and amount applied in sludge.
- Sludge applications are terminated when a cumulative metal limit is reached.

6.4.1 Crop Selection and Nutrient Requirements

It is usually advantageous to maintain or utilize the normal cropping patterns found in the community. These patterns have evolved because of local soil, climatic, and economic conditions, and will probably maintain certain advantages in the sludge application system as well. One possible exception could occur if the cropping pattern was restricted to a single crop. In this case, additional crops could increase the opportunity of applying sludge during a variety of seasons.

The crops grown in an area will influence the scheduling and methods of sludge application. Since sludge applications are typically limited by the N required by the crop, forages, corn, and soybeans will minimize the amount of land needed and the costs associated with sludge transportation and application. However, corn and soybeans actively grow from approximately May to October or November, limiting sludge applications to only a few months of the year. Forage crops, legumes, and grasses are capable of utilizing large amounts of sludge-derived nutrients, but only surface applications are practical on forages that are mowed and baled for animal feed. Injection of sludge into permanent pastures might be acceptable if the farmer is willing to tolerate the negative effects on trafficability. In general, the constraints discussed in previous sections will combine to favor the use of sludge on a mixture of crops such as small grains, cereals, and forages.

Fertilizer recommendations for crops are based on the nutrients needed for the desired yield at a specific level of plant available nutrients in the soil. The amounts of fertilizer N, P, and K required to attain a given crop yield have been determined experimentally for numerous soils in each region of the United States. The crop response has been related to the fertilizer added and the soil test levels for P, K, and trace elements (Zn, Cu, Fe, Mn). As discussed in Section 6.2.1, reliable methods are not available for estimating the plant available N content in most soils. As a result, fertilizer N recommendations are controlled primarily by past experiences with crop yields, and secondarily by the carryover of N from the previous crop grown. This latter point is illustrated by the greater plant available N levels in soil if corn is grown after alfalfa (a legume which fixes atmospheric N_2) versus corn grown after corn (where no N_2 fixation occurs).

For all crops, yield potential and soil fertility are controlled by such factors as the amount and distribution of rainfall, soil physical properties (drainage, crusting, water-holding capacity, and compaction), length of growing season, available heat units, and incidence of weed, insect, and disease problems. All of these factors are integrated into the yield level observed for each crop. For example, two silt loam soils located in a specific county may have identical soil fertility and management levels, but different yield potentials. While one soil historically produces corn at only 247 bu/ha (100 bu/ac), the other soil may be capable of producing 445 bu/ha (180 bu/ac). To design a sludge utilization project, it is essential to obtain local yield information on the potential of crops grown on the specific soil types to be used.

As an illustration of the general approach used, typical midwest relationships between yield level, soil test levels for plant available P and K, and P and K fertilizer requirements are shown in Tables 6-3 through 6-6 for various crops. The amount of supplemental P and K needed by crops increases as the yield level increases for a fixed range of existing plant available P and K in the soil. Conversely, fertilizer needs decrease at a specific yield level as plant available P and K increase. The amounts of N required for each yield level are also shown in Tables 6-3 to 6-6. The data presented in Table 6-7 can be used to correct the N requirements of crops for the amount of plant available N remaining from previous sludge applications. The crop nutrient requirements presented are step functions between yield and fertilizer additions, whereas nutrient uptake is a continuous function of plant available nutrients. Some states recommend fertilizer application rates for a specific yield, rather than a range of yields.

Information on fertilizer recommendations for a specific project can be obtained from the Agricultural Experiment Stations in each state, or from local extension personnel.

6.4.2 Calculation of Residual N, P, and K

When sludges are applied to soils each year, the N, P, or K added in previous years which are not taken up by crops can be partially available during the current cropping season. For example, sludges applied at a rate to meet the N needs of a crop will typically result in increased soil P levels. This same situation could also exist for K with the application of sludge containing high K levels.

The contribution of residual N to plant available N can be significant when sludges are applied each year. Although the largest percentage of mineralizable organic N is converted to inorganic N during the year that the sludge is applied, the continued decomposition of organic N in succeeding years can provide a significant portion of the N needed for crop growth. The amount of N mineralized in sludge-treated soils is dependent on the type of sludge treatment processes used, the ratio of inorganic to organic N in the sludge, and the amount of organic N applied in previous years. A detailed discussion of the N cycle is presented in Appendix B.

TABLE 6-3
REPRESENTATIVE FERTILIZER RECOMMENDATIONS FOR CORN AND GRAIN SORGHUM IN THE MIDWEST

Yield (Metric tons/ha)	Nitrogen to Be Applied (kg/ha)	Fertilizer	Fertilizer P (P_2O_5) and K (K_2O) Recommended for Fertility*†				
			Very Low	Low	Medium	High	Very High
		- - - - - - - - -	- - - - - - - -	- - - (kg/ha) - - -	- - - - - - -	- - - - - -	- - - - - -
6.7-7.4	134	P (P_2O_5):	49 (113)	35 (80)	25 (56)	15 (33)	0
		K (K_2O):	93 (112)	65 (78)	47 (57)	28 (34)	0
7.4-8.4	157	P (P_2O_5):	54 (123)	39 (90)	29 (67)	15 (33)	0
		K (K_2O):	112 (135)	84 (101)	56 (67)	28 (34)	0
8.4-10.1	190	P (P_2O_5):	59 (136)	45 (103)	29 (67)	20 (46)	4 (10)
		K (K_2O):	140 (169)	112 (135)	65 (78)	37 (45)	0
10.1-11.8	224	P (P_2O_5):	64 (146)	49 (113)	35 (80)	25 (56)	4 (10)
		K (K_2O):	167 (201)	130 (157)	84 (101)	56 (67)	0
11.8-13.4	258	P (P_2O_5):	74 (169)	59 (136)	39 (90)	25 (56)	4 (10)
		K (K_2O):	186 (224)	149 (179)	112 (135)	74 (89)	0

* Soil test levels are as follows:

Soil Test	kg/P/ha	kg/K/ha
Very low	0 to 11	0 to 88
Low	12 to 22	89 to 165
Medium	23 to 33	166 to 230
High	34 to 77	231 to 330
Very High	78+	331+

† Amounts of P_2O_5 and K_2O are shown in parentheses.

1 kg/ha = 0.89 lb/ac
1 metric ton/ha = 15.3 bu/ac

TABLE 6-4
REPRESENTATIVE FERTILIZER RECOMMENDATIONS FOR SOYBEANS IN THE MIDWEST

Yield (Metric tons/ha)	Nitrogen to Be Applied (kg/ha)	Fertilizer	Fertilizer P (P_2O_5) and K (K_2O) Recommended for Soil Fertility*†				
			Very Low	Low	Medium	High	Very High
			(kg/ha)				
2.0-2.7	157	P (P_2O_5):	29 (67)	25 (56)	20 (46)	15 (33)	0
		K (K_2O):	99 (119)	74 (84)	47 (57)	37 (45)	0
2.7-3.4	196	P (P_2O_5):	39 (90)	35 (80)	25 (56)	15 (33)	0
		K (K_2O):	112 (135)	84 (101)	56 (67)	56 (67)	0
3.4-4.0	235	P (P_2O_5):	49 (113)	84 (101)	35 (80)	20 (46)	0
		K (K_2O):	140 (169)	112 (135)	84 (101)	56 (67)	0
4.0-4.7	274	P (P_2O_5):	59 (136)	49 (113)	39 (90)	25 (56)	10 (23)
		K (K_2O):	167 (201)	140 (169)	112 (135)	74 (89)	0
>4.7	336	P (P_2O_5):	59 (136)	49 (113)	39 (90)	25 (56)	10 (23)
		K (K_2O):	186 (224)	158 (190)	121 (146)	74 (89)	19 (23)

* See Table 6-3 for definition of soil fertility test levels.

† Amounts of P_2O_5 and K_2O shown in parentheses.

Not recommended with conventional fertilization practices because of N fixation by soybeans.

1 kg/ha = 0.89 lb/ac
1 metric ton/ha = 15.3 bu/ac

TABLE 6-5

REPRESENTATIVE FERTILIZER RECOMMENDATIONS FOR SMALL GRAINS IN THE MIDWEST

Yield (Metric tons/ha)	Nitrogen to Be Applied (kg/ha)	Fertilizer P (P_2O_5) and K (K_2O) Recommended for Soil Fertility*†					
		Fertilizer	Very Low	Low	Medium	High	Very High
		- - - - - - - - - - - - - - - - (kg/ha) - - - - - - - - - - - - - - - -					
WR:1.9-2.8[#]	62	P (P_2O_5):	45 (103)	29 (67)	15 (33)	10 (23)	10 (23)
OB:28-3.4	62	K (K_2O):	84 (101)	56 (67)	28 (34)	0	0
WR:28-3.4	73	P (P_2O_5):	59 (136)	45 (103)	29 (67)	15 (33)	10 (23)
OB:86-100	73	K (K_2O):	112 (135)	84 (101)	56 (67)	28 (34)	0
WR:3.4-4.0	84	P (P_2O_5):	59 (136)	45 (103)	29 (67)	15 (33)	10 (23)
OB:101-115	84	K (K_2O):	112 (135)	84 (101)	56 (67)	28 (34)	0
WR:4.0-4.6	95	P (P_2O_5):	69 (159)	54 (123)	45 (103)	29 (67)	10 (23)
OB:>4.6	95	K (K_2O):	112 (135)	84 (101)	56 (67)	28 (34)	0
WR:>4.6	106	P (P_2O_5):	69 (159)	54 (123)	45 (103)	29 (67)	10 (23)
OB:131+	106	K (K_2O):	112 (135)	84 (101)	56 (67)	28 (34)	0

* See Table 6-3 for definition of soil test levels.

† Amounts of P_2O_5 and K_2O are shown in parentheses.

WR = Wheat and Rye; OB = Oats and Barley.

1 kg/ha = 0.89 lb/ac.
1 metric ton/ha = 14.3 bu/ac for wheat and rye.
1 metric ton/ha = bu/ac for oats and barley.

TABLE 6-6
REPRESENTATIVE FERTILIZER RECOMMENDATIONS FOR FORAGES IN THE MIDWEST

Yield (Metric tons/ha)	Nitrogen to Be Applied (kg/ha)	Fertilizer	Fertilizer P (P_2O_5) and K (K_2O) Recommended for Soil Fertility*†				
			Very Low	Low	Medium	High	Very High
			(kg/ha)				
<1.8	112	P (P_2O_5):	49 (113)	39 (90)	25 (56)	15 (33)	10 (23)
		K (K_2O):	224 (270)	186 (224)	140 (169)	74 (89)	0
2.2-2.7	224	P (P_2O_5):	59 (136)	49 (113)	35 (80)	25 (56)	20 (46)
		K (K_2O):	336 (405)	280 (337)	224 (270)	168 (202)	112 (135)
>2.7	390	P (P_2O_5):	69 (159)	59 (136)	45 (103)	35 (80)	25 (56)
		K (K_2O):	448 (540)	392 (472)	336 (405)	280 (337)	224 (270)

* See Table 6-3 for definition of soil test levels.

† Amounts of P_2O_5 and K_2O are shown in parentheses.

1 kg/ha = 0.89 lb/ac
1 mt/ha = 0.45 T/ac

TABLE 6-7
ESTIMATED PERCENTAGES AND AMOUNTS OF ORGANIC N MINERALIZED AFTER SLUDGE OF VARIOUS TYPES ARE APPLIED TO SOILS (ADAPTED FROM REF. 11)

Time After Sludge Application (Years)	Unstabilized Primary and Waste Activated		Aerobically Digested		Anaerobically Digested		Composted	
	F	K_m	F	K_m	F	K_m	F	K_m
	% of N_o*	kg/mt/% N_o†#	% of N_o	kg/mt/% N_o	% of N_o	kg/mt/% N_o	% of N_o	kg/mt/%N_o
0-1	40	4.00	30	3.00	20	2.00	10	1.00
1-2	20	1.20	15	1.05	10	0.80	5	0.45
2-3	10	0.48	8	0.45	5	0.36	3	0.25
3-4	5	0.22	4	0.21	3	0.21	3	0.25
4-5	3	0.12	3	0.16	3	0.20	3	0.24
5-6	3	0.12	3	0.15	3	0.19	3	0.23
6-7	3	0.12	3	0.15	3	0.19	3	0.23
7-8	3	0.11	3	0.15	3	0.18	3	0.22
8-9	3	0.11	3	0.15	3	0.18	3	0.21
9-10	3	0.11	3	0.15	3	0.17	3	0.21

* Percentage of organic N (N_o) present mineralized during time interval shown. This is the "F" factor in later equations.

† kg N released per metric ton of sludge applied per % organic N in the sludge. For example, application of an anaerobically digested sludge containing 3% organic N at 10 t/ha would result in the following amounts of N mineralization: Year 0, 3% N_o x 10 t/ha x 2.0 = 60 kg N/ha; Year 1, 3.0% N_o x 10 t/ha x 0.80 = 24 kg N/ha; Year 2, 3.% N_o x 10 t/ha x 0.36 = 10.8 kg N/ha. This is the "K_m" factor in later equations.

# Multiply kg/mt by 2 to obtain lb/T.

The approach proposed for evaluating residual N, P, and K is as follows:

- P and K - Assume that 50 percent of the P applied is available for plant uptake. If P in excess of plant needs has been applied in previous years, it can be utilized by the crop grown in the current year. If post-sludge application soil test data are available for P and K, these measured values should be used to assess supplemental P and K fertilizer requirements.

- N - The portion of organic N converted to inorganic N varies for different sludge types during the first year after application to the soil. After the first year, the amount of N mineralization decreases by approximately 50 percent each year until the N mineralization stabilizes at about 3 percent of the remaining organic N. For example, if 20 percent of the organic N was mineralized during the first year, the amounts released in years 2, 3, 4, and 5 would be 10, 5, 3, and 3 percent, respectively, of the organic N remaining (see Table 6-7). The ultimate N mineralization rate of 3 percent was chosen, because it is often observed for stable organic N fractions in soils.

6.4.3 Calculation of Annual Application Rate

Recommended annual rates of sludge application on cropland are based on the N, P, and Cd content of the sludge and the N and P requirement of the crop grown. As discussed in the previous section, the N needs of the crop are corrected for plant available N mineralized from prior sludge additions. There are three basic approaches that can be used to determine the annual application rate:

- Approach 1 - Annual rate applies N equivalent to crop N need and Cd less than regulatory limits.

- Approach 2 - Annual rate applies Cd equal to regulatory limit and N less than crop N need.

- Approach 3 - Annual rate applies P equal to crop P need (N applied < crop N need and Cd applied < current regulatory limit).

For all three approaches, the soil pH must be maintained at 6.5 or greater to minimize metal uptake by crops.

The following section summarizes the basic calculations used to determine sludge application rates. The basic calculations required are similar for all three approaches. The design examples at the end of this chapter illustrate calculations for each approach.

6.4.3.1 Calculation of Nitrogen Applied

The plant available N content in sludge is determined from the total or organic N, NH_4^+-N, and NO_3-N analyses. It is assumed that both NH_4^+ and NO_3^- present in soil after sludge application are available for plant uptake during the cropping season of sludge application. This assumption is consistent with the current practices of applying anhydrous ammonia, ammonium nitrate, ammonium sulfate, potassium nitrate, or urea as nitrogen fertilizers. In contrast to conventional fertilizer materials, however, appreciable amounts of organic N are added to soils in sludges. Mineralization of the organic N provides a slow release of plant available N during the growing season and in future years.

As shown in Table 6-7, the percent of organic N mineralized is generally related to the sludge characteristics resulting from a particular treatment process (11). In general, the greater the degree of sludge processing within the sewage treatment plant, the lower the amounts of organic N released for plant uptake after application to soils. The N mineralization percentages shown in Table 6-7 can be employed to calculate the plant available N content of a sludge, and to correct the fertilizer N recommendation for previous sludge applications. However, there is a significant variation in conversion rates of organic N to in organic N in sludge receiving similar treatment. The mineralization rates shown on Table 6-7 are averages only. It is recommended that incubation studies be done on specific sludges to determine exact mineralization rates.

The amount of plant available sludge-borne N applied to soil is also dependent on the application method used. Recent research has shown that approximately 50 percent of the NH_4^+ is lost to the atmosphere through volatilization of NH_3 when liquid sludges are applied to the soil surface and allowed to dry before being incorporated (see Appendix B). As a result, only 50 percent of the NH_4^+ applied is assumed to be available for plant uptake. For all sludges, the plant available N content (N_p) is determined using the procedures defined below (calculations are performed on a dry weight basis).

The N_p in a particular year is the total of:

- All of the nitrate (NO_3) present in the sludge.
- All or a fraction of the ammonia (NH_4) present in the sludge. If the sludge is liquid and surface-applied, assume that only 50 percent of the NH_4 is plant available, with the remaining 50 percent lost through volatilization during application. However, if the sludge is liquid and incorporated (injected), or dewatered sludge applied in any manner, assume that 100 percent of the NH_4 is plant available.
- A fraction of the organic N (N_o) present in the sludge which is mineralized during the first year after application. This

fraction is represented by the column headed "F" in Table 6-7 for the year 0-1.

- A summation of the N_o in the sludge applied during previous years (if any) which will mineralize during the particular year being calculated. This fraction is represented by the column headed "F" in Table 6-7 for the year(s) since the earlier sludge application.

A two-step calculation is recommended to determine N_p in a particular year.

Step 1, represented by Equation 6-1 below, accounts for the N_p available from the sludge during the first year in which it is applied:

$$N_p = S\,[(NO_3) + K_v\,(NH_4) + F_{(\text{year } 0\text{-}1)}\,(N_o)]\,(10) \qquad (6\text{-}1)$$

where:

N_p = Plant available N from this year's sludge application only, in kg/ha.

S = Sludge application rate, in dry mt/ha.

NO_3 = Percent nitrate-N in the sludge, as percent (e.g., 1% = 1.0).

K_v = Volatilization factor = 0.5 for surface-applied liquid sludge, or 1.0 for incorporated liquid sludge and dewatered sludge applied in any manner.

NH_4 = Percent ammonia -N in the sludge, as percent (e.g., 2% = 2.0).

$F_{(\text{year } 0\text{-}1)}$ = Mineralization factor for organic N in the sludge in the first year (from Table 6-7), expressed as a fraction (e.g., 20% = 0.2). For example, in Table 6-7, anaerobically digested sludge has an F factor for year 0-1 of 20% = 0.2.

N_o = Percent organic N in the sludge, as percent (e.g., 3% = 3.0).

Example of Step 1 Calculation: Assume an application rate of 5 mt/ha, dry weight, of anaerobically digested liquid sludge, which is surface-applied. The sludge chemical analysis shows NO_3 = 0, NH_4 = 1.5%, and N_o = 3%, all on a dry weight basis.

$$N_p = S\,[(NO_3) + K_v\,(NH_4) + F_{(year\ 0\text{-}1)}\,(N_o)]\,(10)$$

$$= 5\,[(0) + 0.5\,(1.5) + (0.2)\,(3.0)]\,10$$

$$= 67.5 \text{ kg } N_p/\text{ha}$$

The reader should note that this calculation computes the N_p only for this year's sludge application, and does not include additional N made available from mineralization of previous years' sludge applications, if any.

Step 2 calculates the N_p available in subsequent years from "this year's" sludge application due to the slow mineralization of N_o in the sludges applied. The mineralization calculations for subsequent years are demonstrated in the following example.

Assume the same sludge application rate and sludge quality as in the previous example, i.e., 5 mt/ha application rate and 3% N_o in the sludge on a dry weight basis.

N_o in sludge applied = (0.03) (5 mt/ha) (1,000 kg/mt) = 150 kg/ha
F factors for anaerobically digested sludge from Table 6-7 are:

Year	F
0-1	0.20
1-2	0.10
2-3	0.05

N_o mineralized in year 0-1 = (0.20) (150) = 30 kg/ha

N_o remaining in year 1-2 = (150) - (30) = 120 kg/ha

N_o mineralized in year 1-2 = (0.10) (120) = 12 kg/ha

N_o remaining in year 2-3 = (120) - (12) = 108 kg/ha

N_o mineralized in year 2-3 = (0.05) (108) = 5.4 kg/ha

A simpler alternate method of calculating the N_o mineralized and made plant available in the first year and succeeding years is to use the K_m factor in Table 6-7 as shown in Equation 6-2 below:

$$N_m = (K_m)\,(N_o)\,(5) \qquad (6\text{-}2)$$

where:

N_m = Quantity of N_o mineralized in the year under consideration, in kg/ha.

K_m = Mineralization factor for the year under consideration (from Table 6-7), in kg/mt/% N_o.

N_o = Percent organic N originally present in the sludge, as percent (e.g., 3% = 3.0).

S = Sludge application rate, in mt/ha.

Example: Assume the same sludge quality and application rate as in the previous examples, i.e., 5 mt/ha application rate and 3% N_o in the sludge on a dry weight basis.

From Table 6-7 for anaerobically digested sludge:

Year	K_m
0-1	2.0
1-2	0.80
2-3	0.36

N_m first year = (2.0) (3) (5) = 30 kg/ha

N_m second year = (0.80) (3) (5) = 12 kg/ha

N_m third year = (0.36) (3) (5) = 5.4 kg/ha

If the sludge is only applied one time, the N_p available in subsequent years is the amount calculated in Equation 6-2. Programs which apply sludge annually are more complex, because the N_o mineralized from all previous years' sludge applications must be included.

Example: Assume annual application of the same quality sludge and sludge application rate as used in the previous examples, i.e., 5 mg/ha application rate and 3% N_o in the sludge. Calculate the N_p available during each of the first 3 years.

Year 0-1 (from Equation 6-1)

$$N_p = S\,[(NO_3) + K_v\,(NH_4) + F_{(\text{year } 0\text{-}1)}\,(N_o)]\,(10)$$

$$= 5\,[(0) + 0.5\,(1.5) + (0.2)\,(3.0)]\,10$$

$$= 67.5 \text{ kg/ha}$$

Year 1-2 (from Equations 6-1 and 6-2)

N_p = N_p from second year plus N_m from first year

$$N_p = 67.5 + (K_m)\ (N_o)\ (S)$$

$$= 67.5 + (0.80)\ (3)\ (5)$$

$$= 79.5 \text{ kg/ha}$$

Year 2-3 (from Equations 6-1 and 6-2)

N_p = N_p from third-year application plus N_m from second-year application plus N_m from third-year application

$$N_p = 67.5 + (0.80)\ (3)\ (5) + (0.36)\ (3)\ (5)$$

$$= 84.9 \text{ kg/ha}$$

The amount of plant available N applied to soil in sludge is determined as described above for all three annual application rate approaches listed at the beginning of Section 6.4.3. For Approach 1, and usually Approach 2, the amount of plant available N applied in the sludge equals the N required by the crop grown.

6.4.3.2 Calculation Based on Metal Limitations

The "Criteria" limit the Cd application on an annual basis, and Cd, Pb, Zn, Cu, and Ni on a total cumulative basis for the site. In either case, the amount of sludge that can be applied (dry weight basis) is calculated with the same basic equation:

$$S_m = \frac{L}{C_m}\ (1{,}000 \text{ kg/mt}) \qquad (6\text{-}3)$$

where:

S_m = Amount of sludge, in mt/ha, that can be applied for the metal and time interval selected (e.g., annual for Cd, or total cumulative for Cd, Pb, Zn, Cu, Ni).

L = Metal limitations, in kg/ha; see Table 6-8 for annual Cd limit, Table 6-2 for cumulative limits.

C_m = Concentration, in mg/kg, of the metal of concern in the sludge being applied.

See sample calculation at end of this chapter.

TABLE 6-8
SUMMARY OF ANNUAL CADMIUM LIMITATIONS (10)

Type of Crop Grown	Annual Cd Limit kg/ha (lb/A)	Comments
Tobacco, root crops, leafy vegetables	0.5 (0.45)	pH $\geq$6.5
Other food chain crops (e.g., corn, small grains, forages)	2.0 (1.78)* 1.25 (1.11)† 0.5 (0.45)#	pH $\geq$6.5
Animal feed only	None	pH $\geq$6.5 · Detailed management plan will also be required.

* Present to 6/30/84.
† 7/1/84 to 12/31/86.
# After 1/1/87.

6.4.3.3 Calculation of Phosphorus Applied

The annual sludge application rate may also be based on the P requirements of the crop grown. It is assumed that the P contained in a sludge is 50 percent as available for plant uptake as the phosphates normally applied to soils in commercial fertilizers (e.g., super and triple super phosphate, diammonium phosphate, etc.). As previously discussed, the P fertilizer needs of the crop grown are determined from the soil test for available P and the yield level of the crop grown. The amount of sludge applied is then equated to the P fertilizer requirement:

$$S_p = \frac{C_p}{P_p} (1{,}000 \text{ kg/mt}) \tag{6-4}$$

where:

S_p = Application rate of sludge, in mt/ha, to satisfy P fertilizer need of crop.

C_p = Plant P needs, in kg/ha.

P_p = Concentration of P in sludge, in mg/kg.

Because the P needs of most crops are approximately 25 percent of the N requirement, the amounts of sludge applied each year with Approach 3 are considerably less than those used with the two other approaches. For nearly all sludges, supplemental N fertilization will be needed to optimize crop yields (except for N-fixing legumes). A major advantage of this approach is that the amounts of Cd applied to soils each year will be less than the Cd limits for nearly all sludges. This approach is the most conservative alternative presented.

6.4.4 Calculation of Fertilizer N, P, and K

The amounts of N, P, and K applied in the sludge should be compared to recommended additions of fertilizer N, P, and K to achieve the yields desired (see Tables 6-3 through 6-6). If this comparison shows that one or more nutrients will be suboptimal, the appropriate amount of commercial fertilizer can be applied. Maximum yields will not result unless all essential plant nutrients are present at recommended levels. In some systems, additional fertilizer may not be applied because of economic considerations.

6.4.5 Termination of Sludge Applications Based on Metal Additions

To protect the productivity of soils and to minimize long-term accumulation of Cd in crops, sludge applications are terminated when the cumulative amounts of Pb, Zn, Cu, Ni, or Cd exceed a specific limit based on the CEC of the soil. Recommended cumulative metal loadings developed in 1977 for privately owned agricultural cropland are shown in Table 6-2. It is imperative that the reader determine if there have been subsequent modifications to these recommendations. As shown, soils are subdivided into three categories based on CEC. Additional comments on total metal limits are presented in Section 6.3.5.

The amounts of Pb, Zn, Cu, Ni, and Cd applied each year are recorded and added to the cumulative metal additions from previous years. Sludge applications cease when any one of the metal limits is reached. When more intensive management and monitoring are employed, and potential crop yield reductions and use restrictions are acceptable, the metal limits shown in Table 6-2 may be exceeded. The dedicated disposal option discussed in Chapter 9 is an example of such a case.

6.5 Monitoring Requirements

The conservative design approaches presented reduce the need for monitoring of soils, crops, and surface and ground water. Since the basic rationale is to utilize sludge as a substitute for commercial fertilizer materials, monitoring of ground water is not usually required, provided that the soil is maintained at pH $\geq$6.5.

Typical monitoring requirements for agricultural utilization of sludge at agronomic rates are summarized in Table 6-9. State and local regulatory agencies must be contacted to obtain monitoring requirements for a specific project.

TABLE 6-9
TYPICAL SITE MONITORING REQUIREMENTS FOR SLUDGE APPLICATION AT OR BELOW AGRONOMIC RATES

Monitoring of:*			
Soil pH	Soil Test for P and K†	NO_3^- in Ground Water	Cd in Crop
Yes (2)#	Yes (2)	No	No

* Numbers in parentheses refer to frequency of analysis: 2 = every 2 years.

† Soil test for available N can be used, if appropriate.

# Frequency depends on amount of N applied, depth to ground water, and amount of leachate. Regulatory agencies will dictate frequency.

The major parameters of concern are (1) pH maintenance at 6.5 to reduce potential metal migration, and (2) soil P and K if optimum crop yields are a project goal. Nitrate in ground water is generally only a problem when the sludge application(s) exceed the N needs of the crop. If the applied N equals crop fertilizer requirement, then potential ground water contamination from sludge is no greater than from the use of conventional fertilizers.

6.5.1 Soil pH

The "Criteria" (10) require maintenance of pH 6.5 or greater to minimize Cd uptake by crops. This pH also reduces the potential for phytotoxicity and leaching of Zn, Cu, and Ni. If soil pH is less than 6.5, an appropriate buffer method is used to determine the amount of limestone or equivalent required for adjusting the soil to pH 6.5. Analyses are performed on a routine basis by soil testing laboratories.

6.5.2 Soil Test for P and K

Analyses are required to determine the amounts of P and K fertilizer needed to optimize crop yields. These analyses are standardized for each region of the United States. In some states, recommendations for fertilizer N are based on soil organic matter or NO_3^- in the soil profile. These analyses should be conducted as needed.

6.5.3 Nitrate in Ground Water

A potential off-site environmental impact following sludge application on land may be NO_3^- leaching into ground water. Ground water monitoring is needed only when the amount of sludge-borne N applied exceeds the N needs of the crop grown. If the N applied equals crop fertilizer requirement, the threat of NO_3^- contamination of ground water from sludge application is no greater than from the use of conventional N fertilizers. Additional information on ground water monitoring is presented in Chapter 11.

6.5.4 Cadmium in Crops

Cd analysis is usually needed only when the annual or cumulative application rate exceeds either the limitations presented in Section 6.3.4 or state or local regulations. Cd analysis is recommended when unforeseen land development results in conversion of non-food chain land to food chain cropland, and where past sludge applications have exceeded the limitations. The plant part sampled will depend on the crop grown. Typically, the harvested portion (fruit, grain, tuber, or leaf) will be sampled and analyzed for Cd. The actual concentration of Cd in plant materials is somewhat meaningless in that the Food and Drug Administration (FDA) has (in 1983) not established acceptable levels of Cd in various crops. If excess Cd is applied, it is strongly recommended that the same crop be grown on an adjacent non-sludge-treated soil of the same type to evaluate the relative increase of Cd in the crop caused by sludge application. The same cultivar (variety) of crop should be grown at the two sites, because Cd uptake can vary for different cultivars.

6.5.5 Other Analyses

Additional site-specific analyses may be needed to monitor the status of some land application systems. For example, soils may need to be analyzed for soluble salts and/or boron in semiarid regions where irrigation is planned. The movement of metals and N can also be assessed by periodically obtaining soil samples to a depth of 2 to 3 m (6 to 10 ft), and analyzing each 30-cm (12-in) increment. Appendix C contains more detailed information.

6.6 Sludge Application Methods and Scheduling

6.6.1 Methods of Application

Methods of sludge application on agricultural land are dependent on the physical characteristics of the sludge and soil and the crops grown. Liquid sludges can be applied by surface spreading or subsurface injection. Surface application methods include spreading by farm tractors, tank wagons, special applicator vehicles equipped with flotation tires, tank trucks, portable or fixed irrigation systems, and ridge and furrow irrigation.

Surface application of liquid sludge is normally limited to soils with <6 percent slopes. It is the normal procedure when forage crops are grown. After sludge has been applied to the soil surface and allowed to partially dry, it is commonly incorporated by plowing or disking prior to planting the crop (i.e., corn, soybeans, small grains, cotton, other row crops). Ridge and furrow irrigation systems can be designed to apply sludge during the crop growing season. Spray irrigation systems generally should not be used to apply sludge to forages or to row crops during the growing season. The adherence of sludge to plant vegetation can have a detrimental effect on crop yields by reducing photosynthesis. In addition, spray irrigation tends to increase the potential for odor problems. Surface application of liquid sludge by tank trucks and applicator vehicles is the most common method for agricultural croplands.

Liquid sludges can also be injected below the soil surface. Available equipment includes tractor-drawn tank wagons with injection shanks (originally developed for liquid animal wastes) and tank trucks fitted with flotation tires and injection shanks (developed for sludge application). Both types of equipment minimize any odor problems and reduce ammonia volatilization by immediate mixing of soil and sludge. Sludge can be injected into soils with up to 12 percent slope. Flotation tires are advantageous to reduce soil compaction and to allow application on soft ground. Incorporation can be used either before planting or after harvesting all crops with the exception of forages. This application method is likely to be unacceptable for forages which are cut and baled, because some injection shanks can either ruin the forage stand or create deep ruts in the field. Specialized equipment for injection in forage is available.

Dewatered sludges are applied to cropland by handling equipment similar to that used for applying animal manures, limestone, or solid fertilizers. Typically, the dewatered sludge will be surface-applied and then incorporated by plowing or disking. Incorporation is not used when dewatered sludges are applied to growing forages. Sludge application methods are discussed in greater detail in Chapter 10.

6.6.2 Scheduling

The timing of sludge applications must correspond to farming operations, and is influenced by crop, climate, and soil properties. Sludge cannot be applied during periods of inclement weather. In some states, sludge cannot be applied to soils that are frozen or covered with snow. Soil moisture is a major consideration which impacts the timing of sludge application. Traffic on wet soils during or immediately following heavy rainfalls may result in compaction and reduced crop yields; muddy soils also make vehicle operation difficult. Application to frozen or snow-covered ground with greater than 3 percent slope may result in excessive runoff into adjacent streams. In addition, sludge applications must be scheduled around the tillage, planting, and harvesting operations for the crops grown. A general guide to allowable times for surface and subsurface applications of sludge for North Central States is shown in Table 6-10. Individual states or local extension personnel can provide similar information.

Split applications of sludge may be required for rates of liquid sludge in excess of 11 mt/ha (5 dry T/ac). Split application involves the addition of smaller quantities of sludge at different times of the year

TABLE 6-10
GENERAL GUIDE TO MONTHS AVAILABLE FOR SLUDGE APPLICATION TO DIFFERENT CROPS IN NORTH CENTRAL STATES*

					Small Grains[†]	
Month	Corn	Soybeans	Cotton[#]	Forages[**]	Winter	Spring
January	S*	S*	S/I	S*	C	S*
February	S*	S*	S/I	S*	C	S*
March	S/I	S/I	S/I	S	C	S/I
April	S/I	S/I	P, S/I	C	C	P, S/I
May	P, S/I	P, S/I	C	C	C	C
June	C	P, S/I	C	H, S	C	C
July	C	C	C	H, S	H, S/I	H, S/I
August	C	C	C	H, S	S/I	S/I
September	C	H, S/I	C	S	S/I	S/I
October	H, S/I	S/I	S/I	H, S	P, S/I	S/I
November	S/I	S/I	S/I	S	C	S/I
December	S*	S*	S/I	S*	C	S*

* Application may not be allowed due to frozen or snow-covered soils in some states; S/I, surface or incorporated application; S, surface application; C, growing crop present; P, crop planted; H, after crop harvested.

† Wheat, barley, oats, or rye.

# Cotton, only grown south of southern Missouri.

** Established forages, legumes (alfalfa, clover, trefoil, etc.), grass (orchard grass, timothy, brome, reed canary grass, etc.), or legume-grass mixture.

to attain the desired total rate. If the sludge contains 4 percent solids, the volume of sludge applied at a rate of 11 mt/ha (5 T/ac) is approximately 89,000 l/ha (23,500 gal ac or about 0.9 ac-in). Realizing that surface runoff depends on soil properties (e.g., infiltration rate) and slope, the likelihood of runoff from relatively flat soils (<5 percent slope) is increased when application rates approach 100,000 l/ha (1 ac-in) of liquid sludge. Obviously, subsurface application will minimize runoff from all soils. An advantage of split application is the increased efficiency of N utilization by the crops grown.

6.6.3 Storage

Storage facilities are required to hold sludge during periods of inclement weather, equipment breakdown, frozen or snow-covered ground, or when access would damage the field or crop. Liquid sludge can be stored in digesters, tanks, lagoons, or drying beds; dewatered sludge can be stockpiled. Volume requirements will depend on individual systems and climate.

The amount of storage capacity needed can be estimated from the following data:

- Sludge volume and physical characteristics.
- Climatological data.
- Cropping data.

An ultraconservative design of storage capacity is for 1 year's production. A more realistic storage volume can be computed from climatological and cropping data.

6.6.3.1 Climatological Data

Sludge applications may be restricted or prohibited in some states on days when >2.5 mm (0.1 in) of rainfall occurs, or when the soils are frozen or snow-covered. For a specific site, the average number of days in each month with these or other weather conditions can be obtained from the National Climatic Center, NOAA, Asheville, North Carolina 28801, or from local sources.

6.6.3.2 Cropping Data

Except for forages, sludge application to cropland is usually limited to those months of the year when a crop is not present. The application schedule shown in Table 6-10 is a general guide for common crops in the North Central States. The availability of sites used to grow a variety of crops clearly facilitates the application of sludge throughout the year. For example, a site containing forages, corn, and winter wheat would permit sludge application during nearly all months of the year. Chapter 10 contains additional information on evaluating sludge storage needs.

6.7 Design Example of Sludge Application Rate Calculations

A detailed design example will be developed for a midwestern city with 20 dry mt/d (22 T/d) of sewage sludge requiring disposal. The sludge has undergone anaerobic digestion, and has the following characteristics:

- Solids - 4.0 percent
- Total N - 2.5 percent
- NH_4-N - 1.0 percent
- Total P - 2.0 percent
- Total K - 0.5 percent
- Pb - 500 mg/kg
- Zn - 2,000 mg/kg
- Cu - 500 mg/kg
- Ni - 100 mg/kg
- Cd - 50 mg/kg
- PCB's - 0.5 mg/kg

Climatological data were collected for the application area as described in Chapter 4. Sludge application will be limited during periods of high rainfall and high soil moisture conditions, because of the potential for surface runoff and the inability to use sludge application equipment. Sludge application will also be limited during periods of extended subfreezing temperatures due to frozen soils.

For this site, assume that:

- Annual sludge applications can not exceed either the N requirement for the crop grown or 2 kg Cd/ha (1.78 lb Cd/ac).

- Soil must be maintained at pH 6.5 or above.

- If the nutrient content of the sludge is not sufficient, then supplemental fertilizer will be used to optimize crop production.

- Annual monitoring is not needed other than routine soil testing to establish fertilizer recommendations and lime requirement.

- The sewage treatment plant monitors chemical composition of the sludge.

- Records are maintained on the amount of sludge applied to each area.

Ground water monitoring will be needed if N applications exceed the N needs of the crop grown. If the Cd applied exceeds the regulatory limit (either annual or cumulative), only animal feed can be grown on the site (10).

Soils in the site area are generally sandy loams, having a CEC of 10 meq/100 g. Representative soil analyses are as follows:

- CEC - 10 meq/100 g
- Soil pH (in water) - 6.0

- Available P - 17 kg/ha (15 lb/ac)
- Available K - 84 kg/ha (75 lb/ac)
- Lime (to pH 6.5) - 5.4 mt/ha (2.4 T/ac)

Crops grown in the area include corn, soybeans, oats, wheat, and forages for hay and pasture. One half of the site is cropped with forages requiring 390 kg/ha (350 lb/ac) of available N per year, and one half is cropped with corn requiring 190 kg/ha (170 lb/ac) available N per year. Crop fertilizer requirements were obtained from Tables 6-2 and 6-5.

Fertilizer recommendations for the two crops are as follows:

Crop	Yield (T/ha)	N	P	K
		(kg/ha/year)		
Corn	8.4-10.1	190	45	140
Forage	2.7	390	59	336

P and K recommendations are based on the soil test data shown above.

6.7.1 Calculation of Initial Annual Sludge Application Rates for Nitrogen

The N_p in the anaerobically digested sludge is calculated based on 100 percent availability of NH_4-N and 20 percent availability of organic N (F = 0.20) during the year of sludge application (see Table 6-7). The sludge does not contain detectable amounts of NO_3-N, so only NH_4-N and total N are needed to determine the N_p. Equation 6-1 is used for this calculation:

$$N_p = S\,[NO_3 + K_v\,(NH_4) + F_{(\text{year } 0\text{-}1)}\,(N_o)]\,(10)$$

Let S (sludge application rate) = 1 mt/ha, then:

$$N_p = (1)\,[(0) + (1)\,(1) + (0.20)\,(2.5 - 1.0)]\,(10)$$

= 13 kg/mt sludge applied to corn

The above calculation is for corn where the sludge is incorporated, making the K_v volatilization factor = 1.

Sludge will be surface-applied on the forage crop, so there will be volatilization losses (K_v = 0.5). For this case:

$$N_p = (1)\,[(0) + (0.5)\,(1) + (0.20)\,(2.5 - 1.0)]\,(10)$$

= 8 kg/mt sludge applied to forage

The sludge application rate required to deliver this amount of N to the crop in the initial year of application can be calculated by substituting the appropriate N values in Equation 6-3.

$$S_N = \frac{C_N}{N_p}$$

Corn (190 kg N/ha/year):

$$S_N = \frac{190\ \text{kg/ha/yr}}{13\ \text{kg}\ N_p/\text{mt sludge}}$$

$$= 14.6\ \text{mt sludge/ha}$$

Forage (390 kg N/ha/year):

$$S_N = \frac{390\ \text{kg/ha/yr}}{8\ \text{kg}\ N_p/\text{mt sludge}}$$

$$= 48.8\ \text{mt sludge/ha}$$

These values are the N-limiting rates for the first year only. In subsequent years, a portion of the previously applied organic N will be mineralized and will become available for plant uptake. (See Section 6.4.3.1 for a discussion and sample calculation.)

6.7.2 Calculation of Annual Sludge Application Rates Using Cadmium Limitation

In addition to considering the annual rate of N addition, the rate of Cd application must be below the prevailing limit if a food chain crop is grown. Assume that the application regulations state that the maximum amount of Cd applied is limited as shown in Table 6-8. The maximum annual sludge application rate is calculated using Equation 6-3 with the appropriate Cd values:

$$S_{Cd} = \frac{L_{Cd}}{C_{Cd}}\ (1{,}000\ \text{kg/mt})$$

$$C_{Cd} = 50\ \text{mg/kg}$$

Present to June 30, 1984:

$$L_{Cd} = 2.0\ \text{kg/ha/year}$$

$$S_{Cd} = \frac{(2)\ (1,000)}{(50)} = 40 \text{ mt/ha/year}$$

July 1, 1984, to December 31, 1986:

$$L_{Cd} = 1.25 \text{ kg/ha/year}$$

$$S_{Cd} \frac{(1.25)\ (1,000)}{(50)} = 25 \text{ mt/ha/year}$$

After January 1, 1987:

$$L_{Cd} = 0.5 \text{ kg/ha/year}$$

$$S_{Cd} \frac{(0.5)\ (1,000)}{(50)} = 10 \text{ mt/ha/year}$$

These Cd limits apply to both the corn and forage crops, since it is assumed that the latter will enter the food chain as animal feed.

A comparison of the sludge application rates based on N and Cd indicates the following:

- Corn - Application of 14.6 mt/ha will not exceed the annual Cd limit until January 1, 1987.
- Forage - Application of 48.8 mt/ha exceeds the current and future Cd limits. Sludge use on forage is limited to 40 mt/ha, resulting in the need for additional N fertilizer to attain optimum yields. The annual application rate will decrease to 25 mt/ha and ultimately to 10 mt/ha.

In all cases, the soil pH must be maintained at 6.5 or above whenever the sludge is applied.

6.7.3 Calculation of Annual Sludge Application and Supplemental Fertilizer Rates for Multi-Year System

The annual application rate based on N required by the crop is calculated after correction of the amount of organic N mineralized from prior sludge applications. The application rate based on N and the associated amount of Cd applied is then compared to the prevailing limitation on Cd additions. The smaller application rate of the two is selected and is used to compute amounts of fertilizer needed to optimize crop yield.

6.7.3.1 Calculation of Annual Application Rate with Correction for Residual Mineralized N

N required by corn = 190 kg N/ha/year

Plant available N in sludge = 13 kg N_p/mt sludge

The mineralized N calculation results are shown for the first 5 years of a sludge utilization system. Assume that initial sludge application is made in 1982, so residual N must be evaluated in 1983. The method is described in Section 6.4.3.1.

For example, if the sludge loading rate = 14.6 mt/ha, initial organic N = 1.5 percent, mineralization rate first year ("F" factor from Table 6-7) = 0.20, and mineralization rate second year = 0.10, then:

Initial organic N in sludge = (0.015) (14.6 mt/ha) (1,000 kg/mt)
= 219 kg/ha

Amount mineralized during application year = (219) (0.20)
= 43.8 kg/ha

Residual at end of application year = 219 - 43.8
= 175.2 kg/ha

Mineralized in second year = (175) (0.10)
= 17.5 kg/ha.

The same results can be obtained by using the (kg N/mt 1% N_o) factors (Factor K_m) in Table 6-7. For example, the second year K_m factor for this sludge would be 0.8, and the amount of organic N mineralized would be:

$$\text{Mineralized N} = (\text{Sludge Loading, } \frac{mt}{ha})\ (\%\ \text{Organic N in Sludge})\ (K_m)$$

(14.6 mt/ha) (1.5% organic N) (0.8) = 17.5 kg/ha

Mineralized N in	Mineralized N (kg/ha)
1982	0
1983	17.5
1984	23.7
1985	27.1
1986	30.3

6.7.3.2 Fertilizer P Needed for Optimum Corn Crop

Corn needs 45 kg P/ha. Assuming 50 percent of sludge P is available, then:

$$P\ \text{available} = (0.02\ P)\ (0.50\ \text{available})\ (1{,}000\ \text{kg/mt})$$

$$= 10\ \text{kg P available/mt sludge}$$

Year	Sludge Applied (mt/ha)	Calculation	Fertilizer P (kg P/ha)
1982	14.6	45 kg P/ha - (14.6 mt/ha x 10 kg P_p/mt)	-101
1983	13.2	45 kg P/ha - (13.2 mt/ha x 10 kg P_p/mt)	-87
1984	12.8	45 kg P/ha - (12.8 mt/ha x 10 kg P_p/mt)	-83
1985	12.5	45 kg P/ha - (12.5 mt/ha x 10 kg P_p/mt)	-80
1986	12.3	45 kg P/ha - (12.3 mt/ha x 10 kg P_p/mt)	-78

The minus (-) value indicates that P additions from sludge are in excess of crop requirements.

6.7.3.3 Fertilizer K Needed for Optimum Corn Crop

Corn needs 140 kg K/ha. Assuming all K in sludge is available to the crop, then:

$$K\ \text{available} = (0.005)\ (1{,}000\ \text{kg/mt})$$

$$= 5\ \text{kg}\ K_p/\text{mt sludge}$$

Year	Sludge Applied (mt/ha)	Calculation	Fertilizer K (kg K/ha)
1982	14.6	140 kg K/ha - (14.6 mt/ha x 5 kg K_p/mt)	67
1983	13.2	140 kg K/ha - (13.2 mt/ha x 5 kg K_p/mt)	74
1984	12.8	140 kg K/ha - (12.8 mt/ha x 5 kg K_p/mt)	76
1985	12.5	140 kg K/ha - (12.5 mt/ha x 5 kg K_p/mt)	78
1986	12.3	140 kg K/ha - (12.3 mt/ha x 5 kg K_p/mt)	79

6.7.3.4 Forage - Sludge Application Rate Limited by Cd

It was determined that the initial application rate of sludge on forages would be 48.8 mt/ha, based on N need. In 1982, this application rate would exceed the Cd limitation of 2 kg/ha. Since the Cd limit decreases in 1984 to 1.25 kg/ha and then to 0.5 kg/ha in 1987, it is obvious that sludge use on forages will provide only a portion of the N required to optimize yield. The amount of sludge applied, based on Cd limits of 2, 1.25, and 0.5 kg/ha, are 40, 25, and 10 mt/ha, respectively. The initial limit will apply to 1982 and 1983, while the intermediate limit will be used for 1984 to 1986. Fertilizer N, P, and K applications will be computed for a 5-year system.

N required by forage = 390 kg N/ha

Plant available N in sludge = 8 kg N_p/mt
(surface application)

Mineralized kg N/ha = mt sludge/ha x % organic N in sludge x kg N_p mineralized/metric for sludge/% organic N

The fraction of organic N mineralized is obtained from Table 6-7, Factor K_m. The amount mineralized each year is summarized below:

Mineralized N in	Mineralized N (kg/ha)
1982	0
1983	48
1984	70
1985	65
1986	69

6.7.3.5 Fertilizer N Needed for Optimum Forage Crop

Fertilizer N needs can be determined by correcting the N requirement of forage for mineralized organic N and sludge N applied as shown below.

Year	(A) Crop Requirement (kg N/ha)	(B) Mineralized (kg N/ha)	(C) Sludge N Applied (kg N/ha)	(A)-(B+C) Fertilizer (kg N/ha)
1982	390	0	40 mt/ha x 8 kg N_p/mt = 320	70
1983	390	48	40 mt/ha x 8 kg N_p/mt = 320	22
1984	390	70	25 mt/ha x 8 kg N_p/mt = 200	120
1985	390	65	25 mt/ha x 8 kg N_p/mt = 200	125
1986	390	69	25 mt/ha x 8 kg N_p/mt = 200	121

6.7.3.6 Calculation of Fertilizer P and K Needs for Optimum Forage Crop

P needed by forage = 59 kg/ha

$$\text{Plant available P in sludge} = \frac{\% \text{ P}}{100} \times 0.5 \times 1{,}000$$

$$= \frac{2.0\% \text{ P}}{100} \times 0.5 \times 1{,}000$$

$$= 10 \text{ kg } P_p/\text{mt}$$

kg fertilizer P/ha = kg P needed/ha - (mt sludge/ha x kg P_p/mt)

Year	Sludge Applied (mt/ha)	Calculation	Fertilizer P (kg P/ha)
1982	40	59 kg P/ha - (40 mt/ha x 10 kt P_p/mt)	-341
1983	40	59 kg P/ha - (40 mt/ha x 10 kg P_p/mt)	-341
1984	25	59 kg P/ha - (25 mt/ha x 10 kg P_p/mt)	-191
1985	25	59 kg P/ha - (25 mt/ha x 10 kg P_p/mt)	-191
1986	25	59 kg P/ha - (25 mt/ha x 10 kg P_p/mt)	-191

K needed by forage = 336 kg/ha

$$\text{Plant available K in sludge} = \frac{\% \text{ K}}{100} \times 1{,}000$$

$$= \frac{0.5}{100} \times 1{,}000$$

$$= 5 \text{ kg } K_p/\text{mt}$$

Year	Sludge Applied (mt/ha)	Calculation	Fertilizer K (kg K/ha)
1982	40	336 kg/ha - (40 mt/ha x 5 kg K_p/mt)	136
1983	40	336 kg/ha - (40 mt/ha x 5 kg K_p/mt)	136
1984	25	336 kg/ha - (25 mt/ha x 5 kg K_p/mt)	211
1985	25	336 kg/ha - (25 mt/ha x 5 kg K_p/mt)	211
1986	25	336 kg/ha - (40 mt/ha x 5 kg K_p/mt)	211

6.7.4 Sludge Application Rate Limited by Phosphorus

The annual rate of sludge application can also be calculated from the P crop needs (some states require this approach). For the soil selected, the fertilizer P needs of corn and forage are 45 and 59 kg/ha, respectively. The annual rates are calculated as follows from the plant available P content of the sludge:

$$P_{available} = (\%\ P \text{ in sludge})\ (50\%\ \text{availability})$$

(Note: Assumes that 0.5 of the total P in sludge is equivalent to conventional P fertilizers with respect to plant availability.)

For this sludge:

$$P_p = (0.02)\ (0.50)\ (1{,}000) = 10 \text{ kg/mt}$$

Equation 6-3 then gives the annual sludge rate as follows:

$$S_p = \frac{C_p}{P_p}$$

For corn:

$$S_p = \frac{(45 \text{ kg P/ha})}{(10 \text{ kg/mt})}$$

$$= 4.5 \text{ mt/ha}$$

For forage:

$$S_p = \frac{59 \text{ kg P/ha}}{10 \text{ kg/mt}}$$

$$= 5.9 \text{ mt/ha}$$

The amounts of Cd applied to corn and forage would be 0.1 and 0.14 kg/ha, respectively. These Cd additions are significantly less than both the 1982 and future Cd limitations.

6.7.4.1 Calculation of N and K Fertilizer Needs for Phosphorus Limiting Design

The annual application rates limited by the P needs for corn and forage are 4.5 and 5.9 mt/ha, respectively. Since these rates are very similar, the calculation of fertilizer N and K will be shown for only corn. In addition, a precise calculation of fertilizer N would include a correction for residual N released from previous sludge applications. The data needed are:

Annual application rate = 4.5 mt/ha

N required by corn = 190 kg N/ha

Plant available N in sludge = 13 kg N_p/mt sludge

K required by corn = 140 kg K/ha

Since the sludge application rate is a constant, the amount of N applied will be the same each year:

$$13 \text{ kg } N_p/\text{mt} \times 4.5 \text{ mt/ha} = 58 \text{ kg } N_p/\text{ha}$$

The mineralized N and fertilizer N needed are calculated from:

Mineralized kg N/ha = mt/ha x % organic N in sludge x (kg N_p mineralized/mt sludge/% organic N)

The fraction (K_m) of organic N mineralized is obtained from Table 6-7. The amount mineralized each year is summarized below:

Mineralized N in	Mineralized N (kg/ha)
1982	0
1983	5
1984	7
1985	8
1986	9

Fertilizer N calculations would then involve:

kg fertilizer N/ha = kg N required by crop/ha - kg sludge N_p added/ha - kg residual N/ha

Year	N Needed by Crop (kg N/ha)	Sludge Inorganic N Added (kg N/ha)	Residual N (kg/ha)	Fertilizer N Needed (kg/ha)
1982	190	58	0	132
1983	190	58	5	127
1984	190	58	7	125
1985	190	58	8	124
1986	190	58	9	123

It is obvious that the amount of fertilizer N needed each year is essentially constant, and will average approximately 125 kg N/ha/year. In view of the uncertainties involved in establishing N fertilizer recommendations, the residual N correction does not need to be used when annual application rates are based on the P needs of the crop.

A single calculation is used to determine the amount of fertilizer K needed because the sludge application rate is constant:

$$\text{Fertilizer K/ha} = \text{kg K needed by crop/ha} - \frac{\text{\% K in sludge}}{100} \times \text{mt sludge/ha}$$

$$= 140 \text{ kg K/ha} - \frac{0.5}{100} \times 4.5 \text{ mt/ha} \times 1{,}000$$

$$= 140 - 22$$

$$= 118 \text{ kg/ha}$$

6.7.5 Calculations of Total Cumulative Amount of Sludge Application

The total amount of sludge that can be applied for the life of a site is based on the cumulative metal loadings, as calculated from the metal content of the sludge and the cumulative metal limits shown in Table 6-2. The maximum amount of sludge which can be applied during the design life of the site is calculated with Equation 6-3:

$$S_m = \frac{L_m}{C_m} (1{,}000 \text{ kg/mt})$$

For lead:

$$S_{Pb} = \frac{L_{Pb}}{C_{Pb}} (1{,}000 \text{ kg/mt})$$

$$= \frac{1,120}{500} (1,000 \text{ kg/mt})$$

$$= 2,240 \text{ mt/ha}$$

For the sludge in this example:

Metal	Total Metal Limit (kg/ha)	Metal Content of Sludge (mg/kg)	Calculation		Total Amount of Sludge Allowed (mt/ha)
Pb	1,120	500	$\frac{1120}{500} \times 1000$	=	2,240
Zn	560	3,000	$\frac{560}{3000} \times 1000$	=	187
Cu	280	500	$\frac{280}{500} \times 1000$	=	560
Ni	280	200	$\frac{280}{200} \times 1000$	=	1,400
Cd	10	50	$\frac{10}{50} \times 1000$	=	200

In this case, Zn will limit the total cumulative sludge loading to 187 mt/ha. The site life is then a function of the loading rates previously derived.

For corn, the average rate after the first 2 years is about 12 mt/ha per year. The useful life would then be 187/12, or 15.6 years.

For forages, the rate was controlled by Cd and ranged from 40 mt in 1982 to 10 mt in 1987. On that basis, the useful life would be about 8 years.

6.7.5.1 Phosphorus Limiting Design

The sludge loading rate was 4.5 mt/ha for corn and 5.9 mt/ha for forages. The useful life is then as follows:

Corn $\frac{187}{4.5} = 41.5$ years

Forages $\frac{187}{5.9} = 31.7$ years

6.7.6 Area Requirement

The amount of sludge produced per year is 6,600 mt, of which 50 percent is to be applied to corn and 50 percent to forage.

6.7.6.1 N and Cd Basis

a. Corn - Incorporated Application

$$\text{Area needed} = \frac{3{,}300 \text{ mt/yr}}{12 \text{ mt/ha/yr}} = 275 \text{ ha}$$

b. Forage - Surface Application

From 1982 to 1983:

$$\text{Acreage needed} = \frac{3{,}300 \text{ mt/yr}}{40 \text{ mt/ha/yr}} = 82.5 \text{ ha}$$

In 1984 and 1985:

$$\text{Acreage needed} = \frac{3{,}300 \text{ mt/yr}}{25 \text{ mt/ha/yr}} = 132 \text{ ha}$$

6.7.6.2 P Basis

a. Corn - Incorporated Application

$$\text{Acreage needed} = \frac{3{,}300 \text{ mt/yr}}{4.3 \text{ mt/ha/yr}} = 767 \text{ ha}$$

b. Forage - Surface Application

$$\text{Acreage needed} = \frac{3{,}300 \text{ mt/yr}}{5.9 \text{ mt/ha/yr}} = 559 \text{ ha}$$

6.7.7 Storage

As with virtually all agricultural land sludge application programs, sludge storage facilities will be required for this design example. Chapter 10 contains a discussion of the factors used to estimate required sludge storage capacity. State regulatory agencies will sometimes stipulate the minimum number of days of sludge storage required.

6.7.8 Application Scheduling and Operations

Table 6-11 presents a possible schedule for a typical midwestern city to apply sludge to corn and forage crops. The table shows that no sludge application can be made during the period December through February. Sludge application to forage can be made from March through November, and sludge can be applied to corn in March, April, October, and November.

TABLE 6-11
TYPICAL MONTHS OF THE YEAR WHEN SLUDGE CAN BE APPLIED TO CORN AND FORAGE FOR DESIGN EXAMPLE*

Month	Corn	Forage
January	NA	NA
February	NA	NA
March	SI	S
April	SI	S
May	C	S
June	C	S
July	C	S
August	C	S
September	C	S
October	SI	S
November	SI	S
December	NA	NA

* NA = no application (e.g., frozen ground); S = surface application; SI = surface or injection application; C = growing crop present.

6.7.8.1 Transportation and Application Methods

After deciding upon an area for sludge application, the various alternatives for transportation and application methods can be considered. Costs for transportation can be estimated from data presented in Chapter 10.

6.7.8.2 Monitoring

This design example is based on minimizing both NO_3-N movement into ground water and Cd uptake by plants. Therefore, monitoring for these parameters should not be necessary. The monitoring program would consist of continuing soil analysis every 2 to 4 years for plant available P and K and lime requirement. To preclude excessive plant availability of metals, primarily Cd, the soil must be maintained at pH >6.5.

6.7.8.3 Additional Cropping Patterns

To simplify the design example, only two crops were considered. However, in many situations, sludge can be applied to more than two crops. It is suggested that application rate calculations be made for all crops grown when a detailed plan is developed. For this design example, additional crops could be wheat, oats, barley, and soybeans. Crop rotations are commonly used in many areas (e.g., corn-soybeans, soybeans-winter wheat, and forage-corn-oats-forage).

6.8 References

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CHAPTER 7

PROCESS DESIGN FOR FOREST LAND UTILIZATION

7.1 General

The purpose of this chapter is to present design information for the utilization of sewage sludge on forest land. All of the information provided was derived from research, demonstration projects, experience with agricultural crops, and extrapolation of research experience. In 1982, there were no operating full-scale sludge-to-forest land programs identified in the United States. However, the cities of Seattle and Bremerton, Washington, were in advanced planning stages for such programs, and the interested reader may wish to contact these cities in the future for operational information. Operational research and demonstration projects were also located in Washington, Michigan, and South Carolina (see Table 7-1).

In 1982, no federal regulations existed which specifically addressed the application of sludge to forest lands beyond the general requirements of 40 CFR 257. Several states (e.g., Michigan, New York, Minnesota, Washington, and Oregon) were developing proposed regulations. Project planners and designers are advised to obtain applicable regulatory information from appropriate state and federal agencies. The design approach taken in this chapter assumes that the chemical, biological, and physical reactions of sludge and soil in forest applications are generally similar to those in agricultural applications (see Chapter 6).

Based on demonstration and research results, properly managed application of sludge to forest lands is feasible. Trees have been shown to respond positively to nutrient additions, especially when forest soils are low in N, and surface litter layers have comparatively high N storage (immobilization) capacity. Because forests are perennial, application scheduling is often more flexible, and less sludge storage is required than with the agricultural option. Finally, in many regions, forest land is extensive, and provides a reasonable sludge application alternative to agricultural cropland.

Application of sludge to forest land is feasible on commercial timber and fiber production lands, federal and state forests, and privately owned woodlots. Sludge use in nurseries, green belt management, and Christmas tree production is also possible, but will not be specifically addressed in this chapter.

Sludge applications to forest land will be discussed for three common situations: (1) recently cleared forest land that has not been planted, (2) young plantations (planted or coppice), and (3) established forest stands. Each of these cases presents different design problems and opportunities which must be considered.

TABLE 7-1
SELECTED SLUDGE-TO-FOREST LAND RESEARCH AND DEMONSTRATION PROJECTS (1982)

Locations and Agency Contacts	Brief Description	References
Atlanta, Michigan (Department of Natural Resources, Municipal Wastewater Division Lansing, Michigan)	1 application of 11 mt/ha sludge to 6 ha (15 ac) northern hardwoods, aspen sprouts, jack pine plantation and pole-size oak.	Study in progress
Cadillac, Michigan (USDA Forest Service 1407 S. Harrison Road E. Lansing, Michigan)	1-2 applications of a range of sludge dosages to experimental plots in aspen, pine plantings, and clearcuts.	12, 23, 84
	Single application at 10 mt/ha to 24 ha (60 ac) of cutover jack pine, 1978-1979.	23
	Single sludge application in 1980 to 5 ha (12 ac) cutover jack pine for wildlife habitat effect studies.	Study in progress
Elbert County, Georgia (USDA Forest Service Carlton Street Athens, Georgia)	Sludge application to an eroded forest site, approximately 2 ha, at varying rates up to 69 mt/ha, species are loblolly and short leaf pine.	6
Savannah River Laboratory (Aiken, South Carolina Savannah River Lab 733-11A Aiken, South Carolina)	Extensive sludge application R&D program, site is approximately 15 ha, using various ages and species of trees, varying types and application rates of sludge up to 700 kg N/ha dry weight.	24
Pack Forest (College of Forest Resources University of Washington Seattle, Washington)	Sludge application to Pack Forest as well as extensive green house studies species native to the Pacific Northwest.	22
Seattle, Washington (Municipality of Metropolitan Seattle)	Application of sludge to test plots in forest lands since 1973.	63
Zanesville State Tree (Nursery, Ohio Dept. of Forestry OARDC Wooster, Ohio)	Sludge application to Christmas tree production plots.	52
City of Hagerstown (Hagerstown, Maryland)	Sludge application to hybrid poplars, to be used for electricity production.	Pilot-scale project and scale-up in progress
Bremerton, Washington (College of Forest Resources, University of Washington, Seattle, Washington)	Sludge application to forest land (53 ha) research program begun in 1971.	8

Public participation considerations are a critical aspect of planning for forested systems. Chapter 3 contains a detailed discussion on this topic.

7.2 Site Investigations and Selection Criteria

Chapter 5 of this manual discussed in detail the process involved in the identification, evaluation, and selection of sites for land application of sludge. This chapter will discuss those special aspects unique to use of forested lands for sludge. Data sources are the same as those described in Chapter 5, and typically include topographic maps, soil surveys and maps, soil chemical characteristics, and site observations.

7.2.1 Physical Features

The physical features to consider include:

- Proximity to public access, e.g., recreational areas, inhabited dwellings, public roads, hiking trails, etc. The sludge application site(s) should be as distant from normal public access as practical. Many states have regulations for minimum setbacks (buffer zones) which were developed for agricultural sludge application. Applicable state and/or local regulations should be reviewed. Table 5-7 in Chapter 5 summarizes suggested setback distances for agricultural sludge application sites. Except perhaps in the case of cleared land, forest applications are virtually always surface applications, and the criteria in Table 5-7 for that case can generally apply to forested sites.

- Proximity to surface waters (e.g., ponds, lakes, springs, creeks, streams, rivers, etc.). The sludge application site(s) should be located and managed to avoid contamination of surface waters. Various states require setbacks of 90 to 450 m (300 to 1,500 ft) from the 10-year high water mark of such existing surface waters. The purpose of the setback is to prevent sludge constituents from migrating from the application site to the surface waters. If the application site has steep slopes and/or relatively impervious soil, runoff will be greater and setback distances should be increased. Conversely, a flatter site (e.g., less than 6 percent slope) with good soil permeability and heavy vegetation will limit sludge constituent movement, and less setback is necessary.

- Proximity to watersheds used for drinking water supplies. These areas should generally be avoided for sludge application. Where conditions dictate use of water supply sensitive sites, special provisions should be made in the program for sludge quality control, minimization of sludge constituent migration, and monitoring of surface and ground water quality.

- Proximity to water supply wells. Depending upon the geology in the area, a minimum setback distance of 90 to 450 m (300 to 1,500 ft) is suggested.

- Distance to ground water table. It is suggested that application sites have a minimum ground water table of 1 m (3 ft) average, and 0.7 m (2 ft) minimum below the soil surface. The purpose of this stipulation is to prevent seasonal surface flooding (i.e., boggy conditions), which could cause sludge migration. If the ground water is a drinking water aquifer, it is suggested that the minimum distance to the seasonal high water table be increased to 2 m (6 ft) below the soil surface, in order to minimize leaching of sludge contaminants into the aquifer.

7.2.2 Topography

The slope of the land surface is a major factor influencing the potential for surface runoff following sludge application. Table 5-2 in Chapter 5 presents recommended slope criteria.

7.2.3 Soil Characteristics

7.2.3.1 Soil pH

Forest soils are typically more acidic than agricultural sites; soil pH values of 5.5 and lower are common. For agricultural applications, the EPA and many states require that the pH must be at or above 6.5. This pH limit is stipulated because trace metal availability in the soil rapidly increases as soil pH decreases. Increased metal availability in agricultural soils increases crop uptake of metals, possibly resulting in plant phytotoxicity and/or the unsuitability of the crop for human consumption. In addition, metal migration into aquifers could result when soil pH is low.

Experience with sludge applications to forest soils in established forests indicates that the increased metals available due to lower soil pH do not cause phytotoxicity in most forest plant species (3)(9) (45)(84). In addition, because forest products are not food chain crops, increased metal content of the plants themselves is not a concern for public health. For these reasons, the appropriate regulatory agency can be asked to waive the 6.5 soil pH lower limit, if there is no danger of trace metal migration to useful aquifers.

7.2.3.2 Nutrient Availability

Forest soils, particularly in the Pacific Northwest, can be deficient in organic nutrients, and are low in available N. In some special cases, it may be possible to make up this original deficit with an additional amount of sludge organic N without adverse impacts on the ground water.

7.3 Constraints

The major constraints associated with application of sludge to forest lands are related to specific sludge constituents, including pathogens, N, and metals. Each of these sludge constituents is discussed in the following subsections in relation to proper system design and management needed to protect public health and application site ecology. The constraints discussed herein are adapted, where applicable, from agricultural sludge application criteria, experience with demonstration projects, and opinions of experts involved in preparation and review of this manual.

7.3.1 Pathogens

Pathogens are discussed in Appendix A. Sludge application to forest soil, following the criteria in Section 7.2.1, should pose minimal pathogen contamination danger to ground water supplies.

Prevention of surface water contamination depends on the selection and proper operation of application sites. Desirable characteristics are as follows:

- Distant from sensitive surface water resources.
- Experience little surface runoff because of:
  - Relatively flat slopes
  - Permeable soil
  - No steep clearcuts
  - Forest canopy which intecepts rainfall
  - Forest debris layer at the soil surface.

Another pathogen-related concern involves windborne contamination resulting from spray application of liquid sludge on forest lands. It is suggested that the following constraints be used during spray application of sludge to forest lands:

- The public be restricted from an area at least 490 m (1,500 ft) downwind during the spray application, and for several hours after spraying is completed.
- Sludge spraying not be performed during winds of more than 24 km/hr (15 mi/hr); windless conditions are preferred.

It is obvious that aerosols will not travel far in an established forest that is not dormant, because of interception by the leaves and breakup of wind currents, and the suggested constraints listed above may be modified. Public access to the application site has been limited for a period of 12 months following liquid sludge application at projects in Michigan and Washington.

7.3.2 Nitrogen

7.3.2.1 General

The application rate calculation based on N involves the following steps:

1. Calculate the quantity of inorganic N (NH_4 and NO_3) per ton in sludge (Section 6.4).
2. Calculate the quantity of organic N per ton in sludge, and estimate the mineralization rate of the organic N in the first year after application and in succeeding years (Section 6.4).
3. Tabulate the N additions represented by Items 1 and 2 above.
4. Estimate the N uptake by trees and other forest vegetation in terms of kg/ha (lb/ac) (Table 7-2).
5. Estimate the ammonia volatilization in terms of percent of ammonia N (NH_3) applied (Chapter 6).
6. Tabulate the N removals represented by Items 4 and 5 above, for the first year and succeeding years in terms of kg of N removed/ha (lb/ac).
7. Determine the allowable nitrogen input to the groundwater at the project boundary. In special cases, drinking water limits may prevail.
8. Calculate the quantity of sludge which can be applied to the site without exceeding the capacity of the site to remove the necessary amount of N in the applied sludge. In cases where ground water is not used for human consumption, or where the aquifer is large enough to quickly dilute nitrates leaching at the application site, the N loading to the site may be increased. Each case should be evaluated in a site-specific manner.

7.3.2.2 Nitrogen Uptake by Trees and Other Forest Vegetation

There is a significant difference between tree species in their uptake of available N. In addition, there is a large difference between the N uptake by seedlings, vigorously growing trees, and mature trees. Finally, the extent of the vegetative understory on the forest floor will affect the uptake of N, i.e., dense understory vegetation markedly increases N uptake.

In a forest ecosystem, much of the N uptake by the trees is returned to the soil as needle, leaves, and litter fall. Thus, the net N uptake is usually significantly less than the gross N uptake by the growing trees and understory.

TABLE 7-2
ESTIMATED ANNUAL NITROGEN REMOVAL BY FOREST TYPES (81)*

	Tree Age (years)	Average Annual Nitrogen Uptake (kg/ha/yr)†
Eastern Forests		
Mixed Hardwoods	40-60	200
Red Pine	25	100
Old Field with White Spruce Plantation	15	200
Pioneer Succession	5-15	200
Aspen Sprouts	-	100
Southern Forests		
Mixed Hardwoods	40-60	280
Southern Pine with No Understory#	20	200
Southern Pine with Understory#	20	260
Lake State Forests		
Mixed Hardwoods	50	100
Hybrid Poplar**	5	150
Western Forests		
Hybrid Poplar**	4-5	300
Douglas Fir Plantation	15-25	200

* Uptake rates shown are for wastewater irrigated forest stands.

† Conversion factor kg/ha = 0.89 lb/ac.

# Principal southern pine included in these estimates is loblolly pine.

** Short-term rotation with harvesting at 4 to 5 years; represents first growth cycle from planted seedlings.

Table 7-2 provides estimates of annual N uptake by the overstory and understory vegetation of fully established and vigorously growing forest ecosystems in selected regions of the United States. The average annual N uptakes reported vary from 100 to 400 kg/ha/year (89 to 356 lb/ac/year), depending upon species, age, etc. Note that all of the trees listed in the table are at least 5 years old, and that during initial stages of growth, tree seedlings will have relatively lower N uptake rates than shown. Net N uptake may be only 5 to 50 percent of that shown in Table 7-2.

7.3.2.3 Nitrification-Denitrification Reactions

Nitrogen loss by denitrification is discussed in detail in Appendix B of this manual. Generally, little N removal by denitrification is expected in typical well drained forest soils.

7.3.2.4 Ammonia Volatilization

For design purposes, volatilization losses can be estimated at 50 percent of the ammonia N applied to the soil surface in liquid sludges; the entire loss occurs in the first year after application. If liquid sludge is incorporated or if dewatered sludges are applied, the design should not assume any specific losses via volatilization.

However, based on wastewater irrigation experience, it can be shown that 10 to 15 percent of the inorganic N applied each year cannot be accounted for. The assumed pathways are volatilization and denitrification losses. It is reasonable to expect a similar level of loss from sludge applications. However, these losses are not additive, so that if a 50 percent credit has already been taken for volatilization of ammonia in liquid sludge, this additional credit is not appropriate. If no credits are taken for volatilization or other gaseous losses, it would be conservative to assume that 10 percent of the inorganic N in sludges is lost during the application year in forested systems.

7.3.3 Cumulative Metal Loadings

7.3.3.1 General

The interaction of metals in sludge with soils is discussed in Appendix B. Generally, metals in sludge are considered less a potential problem in sludge application to forest lands than in application to agricultural crops, because forest vegetation is not part of the human food chain. For proposed forest land applications, it may be possible to obtain regulatory waivers of annual metals limits.

7.3.3.2 Calculation of Cumulative Metal Loadings

For very conservative designs, it is suggested that cumulative metal loadings to forest lands adhere to the same Criteria stipulated in Chapter 6 for agricultural lands. These limits are shown in Table 6-2. However, for forest application, the stipulation in Table 6-2 that the soil must be maintained at pH 6.5 or above should be waived. The Cd limit need not be applied to forest lands since food chain crops would not be grown, and Cd toxicity to forest vegetation is not a serious concern. Note that Table 6-2 relates the metal loading limits to soil cation exchange capacity (CEC). For forest application, the designs will generally use the middle column of Table 6-2 (applicable to soil CEC of 5 to 15 meq/100 g), as repeated below.

Metal	Maximum Cumulative Loading (kg/ha)
Pb	1,120
Zn	560
Cu	280
Ni	280

There was insufficient data available at the time that this manual was prepared to determine limits of metal phytotoxicity for various tree species, although research does indicate that limits can be more liberal than for agricultural crops. Based on agricultural crop limits, it is probable that the cumulative metal limits can be exceeded for most tree species without creating phytotoxic conditions.

7.4 Effect of Sludge Additions on Tree Growth and Wood Properties

Accelerated tree growth (200 to 300 percent) resulting from sludge addition has the potential for changing basic wood characteristics, including specific gravity, shrinkage, fibril angle, and certain mechanical properties. Research to date indicates that both positive and negative effects on wood quality occur in trees grown on sludge-amended soil. The static bending tests which show the combined effects have shown no significant change when the strength properties of specimens cut from trees grown on sludge-amended soils were compared with specimens of wood produced without sludge.

7.5 Comparison of Sludge Application to Forest Land in Various Stages of Growth

The designer may have the option of selecting forest land sites for sludge addition which are:

- Recently cleared prior to replanting.
- Young plantations in the range of 2 to 5 years old.
- Established forests.

There are advantages and disadvantages to be considered in each type of forest site. These are summarized in Tables 7-3 to 7-5.

TABLE 7-3
SLUDGE APPLICATION TO RECENTLY CLEARED FOREST SITES

Advantages

1. Better access for sludge application equipment. Also, optimal access can be established for additional sludge application in the future.
2. Possible option of incorporating the sludge into the soil (versus a surface application) if the site is sufficiently cleared.
3. Possible option of establishing ridge and furrow, or flooding sludge application system (versus spray application) if the site topography is favorable.
4. Option to select tree species which show good growth and survival characteristics on sludge amended sites.
5. Often easier to control public access to the site because cleared areas are less attractive than wooded areas for typical forest recreational activities.

Disadvantages

1. Seedlings of some tree species show poor survival when planted directly in freshly applied sludge. It may be necessary to let the sludge age for 6 months or more, to allow salt leaching, ammonia volatilization, etc. However, deciduous species and many conifers, including Douglas fir and Sitka spruce, have shown excellent tolerance to sludge in demonstration projects.
2. Seedlings have low nitrogen uptake rates. If nitrate contamination of an underlying potable aquifer is a potential problem, initial sludge applications must be small relative to the volume of sludge application to established forests.
3. An intensive program of weed control is necessary since the weeds grow faster than the seedlings, and compete for nutrients, space, light, etc. Use of herbicides and cultivation between tree rows is usually required for the first 3 to 4 years.
4. Intensive browsing by deer and damage to young trees by voles and other pest species may require special control measures, since these animals may selectively feed upon trees grown on sludge-amended sites due to their higher food value.

TABLE 7-4
SLUDGE APPLICATION TO YOUNG FOREST PLANTATIONS (OVER 2 YEARS OLD)

Advantages

1. Seedlings are established and more tolerant of fresh sludge applications.
2. Weed control is less of a problem than with cleared sites because of established trees and vegetation.
3. Nitrogen uptake by the trees is rapidly increasing and acceptable sludge application rates can be higher on sites over sensitive aquifers.
4. Access for sludge application equipment is usually still good.
5. Rapid growth response from most deciduous and many coniferous tree seedlings can be expected.

Disadvantages

1. Sludge application by spraying over the canopy may be restricted to those periods when the trees are dormant, to avoid the problem of sludge clinging to foliage. If application can be planned shortly before heavy rainfall, this problem can be circumvented by the washing effect of the rain.
2. Some weed control will still probably be necessary.
3. Plant nitrogen uptake rate is less than that of a well-established forest cover.

TABLE 7-5
SLUDGE APPLICATION TO CLOSED ESTABLISHED FORESTS (OVER 10 YEARS OLD)

Advantages

1. Established forest land is often more readily available in sufficient area (size) and closer distance to sewage treatment plants than cleared sites or young plantations.
2. Established forests are less susceptible to sludge-induced changes in vegetation (e.g., weed growth).
3. Plant nitrogen uptake is higher, allowing more sludge to be applied without exceeding nitrogen limits necessary to prevent nitrate leaching to sensitive aquifers.
4. Excellent growth response can be expected to result from the increased nutrients. This is not true of old trees, however. What is "old" varies between species, but generally lies between 30 and 60 years.
5. Sludge application by spraying can be done under the tree foliage, so it is not necessary for the trees to be dormant.
6. During precipitation, rapid runoff of storm water containing sludge constituents is unlikely, because the forest canopy breaks up the rain, and accumulated organic debris on the forest floor absorbs runoff.
7. Forest soils under established forests usually have high C-to-N ratios resulting in excellent capability to immobilize (store) nitrogen for slow release in future years. Consequently, it is often feasible to make an initial heavy application of sludge, e.g., 60 kg/ha (54 T/ac), and achieve excellent tree growth response for up to 5 years without subsequent sludge applications.

Disadvantages

1. Access by sludge application vehicles into a mature forest is often difficult. The maximum range of sludge spray cannons is about 40 m (120 ft). To obtain fairly uniform coverage, the spray application vehicle requires access into the site on a road grid, spaced at approximately 75-m (250-ft) intervals. Most established forest sites are not provided with grid-like roads. As a result, access roads must be cut through the forest, or the selected sludge application area(s) are largely restricted to narrow 36-m (120-ft) strips on both sides of existing roads. Access into commercial forests is usually easier than into publicly owned forest lands.
2. Control of public access is usually more difficult in an established forest. If the sludge is applied to narrow strips adjacent to existing roads, the potential problem may be of more concern. Again, use of commercial forest may mitigate the control of public access.
3. In an established publicly owned forest, it may not be advantageous to accelerate vegetation growth with sludge applications. In contrast, commercial forest operations desire faster growth of trees.

7.6 Design Example of Sludge Application to Forested Lands

Part of this design example is developed to demonstrate the procedures needed to ensure protection of drinking water aquifers during an annual sludge application program. As a result, the values are very conservative. In the general case, it is more typical to apply a single, larger quantity of sludge every 3 to 5 years. The total amount of sludge applied is based on the nutrient needs of the forest vegetation over the 3- to 5-year period. However, this may result in nitrate migration to ground water during the first year. If site conditions allow such an impact to occur, it will usually be more economical to apply a larger quantity of sludge every 3 to 5 years (see the design example in Chapter 8 for this case). The criteria used for this example are as follows:

1. Nitrogen application not to exceed the ability of the forest plants to utilize the N applied with appropriate credit for losses.

2. Cumulative metal loading limits not to exceed those generally allowed for cropland. The major departure for this case is that forest soil pH can be lower than the pH 6.5 recommended for agriculture. In addition, if the site is ever to be converted to food chain agriculture, then the cumulative Cd limits will also apply. If the site will always remain a forest or be used for other non-food chain purposes, then Cd limits should not apply.

7.6.1 Sludge Quantity and Quality Assumptions

The sludge generated by the hypothetical community in this example is assumed to have the following average characteristics:

- Anaerobically digested sludge generated in the average amount of 18.2 mt/day (20 T/day), dry weight, by an activated sludge sewage treatment plant.

- Liquid sludge averages 4 percent solids by weight; its volume is 445,600 l/day (117,600 gal/day).

- Average sludge analysis on a dry weight basis is:

Organic N	3 percent by weight
NH_4N	1 percent by weight
NO_3	None
Pb	500 mg/kg
Zn	2,000 mg/kg
Cu	500 mg/kg
Ni	100 mg/kg
Cd	50 mg/kg

7.6.2. Site Selection

The hypothetical community is located in the Pacific Northwest. A large commercial forest is located 24 km (15 mi) from the sewage treatment plant. The grower believes that he can expect a significant increase in tree growth rate resulting from the nutrients in the sludge. Preliminary investigations of the grower's property shows that a total of 3,000 ha (7,400 ac) are available, of which 1,200 ha (3,000 ac) have the following desirable characteristics:

- Convenient vehicle access from public and private roads, plus an in-place network of logging roads within the area.
- No surface waters used for drinking or recreational purposes are located within the area. Intermittent stream locations are mapped, and 90-m (290-ft) (or greater) buffer zones can be readily established around the stream beds.
- Ground water under one portion of the site has the potential to serve as a drinking water aquifer.
- Public access is limited by signs and fences adjacent to public roads.
- Topography is satisfactory, in that the area consists largely of slopes less than 6 percent, and slopes steeper than 30 percent can be readily excluded from the sludge application program.
- There are no residential dwelling units within the area.
- The area is roughly equally divided between young plantations 2 to 4 years old and an established forest. However, the 1,200 ha (3,000 ac) contains an area of 200 ha (500 ac), which contains tree species which have undocumented response to sludge addition. This area is excluded.

7.6.2.1 Soil and Hydrological Properties of the Site

The soils are of two types: glacial outwash, and residual soil developed from andesitic bedrock. The glacial outwash is located largely on terraces with slopes less than 10 percent. Infiltration is rapid. The soil pH ranges between 5.5 and 6.0, and CEC is 14 meq/100 g. A 2.5- to 5.0-cm (1- to 2-in) litter layer exists in the established forest. The ground water table is approximately 9 m (30 ft) below the soil surface.

Residual soil is found on slopes ranging up to 40 percent. Slopes steeper than 30 percent were eliminated from further consideration.

7.6.3 Calculate the Sludge Application Rate

Assume that the sludge is to be applied on an annual basis, and that the quantity of sludge applied is limited by N. The purpose of the calculation is to have the plant-available N in the applied sludge equal the N uptake of the trees and understory, plus assumed denitrification losses discussed in Section 7.3.2.4. This is a conservative approach intended to prevent leaching of nitrate to the ground water aquifer.

a. Step 1 - Calculate the amount of available N per ton of sludge applied in the first year. Available N_p = (NH_4-N) - (NH_4-N volatilized) + (organic N x % mineralization rate in the first year) - (losses unaccounted for), all on a dry weight basis.

where:

- NH_4-N = 1% by weight = 10 kg/mt (20 lb/T).
- Organic N = 3% by weight = 30 kg/mt (60 lb/T).
- NH_4-N volatilized = 50% of NH_4 in sludge, an assumption for surface-applied liquid sludge.
- Percent organic N mineralized = 20% in the first year, an assumption (see Table 6-7).
- Percent of losses unaccounted for is assumed to be zero for surface-applied liquid sludge, for which we have already subtracted 50 percent of the NH_4-N during application.
- Available N in first year = 10 - (10 x 0.5) + (30 x 0.2) = 11 kg/mt (22 lb/T) of applied sludge.

b. Step 2 - Calculate the amount of available N per ton of sludge applied in succeeding years, including the effect of organic N mineralization from previous years' sludge applications. Available N = (NH_4-N) - (NH_4-N volatilized) + (organic N x % mineralization rate in first year) - (losses unaccounted for) + (organic N applied in previous years x % mineralization rate for previous years), all on a dry weight basis.

where:

Assumed organic N mineralization rates from previous years' sludge applications are taken from Table 6-7, as follows:

Year	Rate
0-1	0.20
1-2	0.10
2-3	0.05
3-4	0.03
4-5	0.03

First Year

N_p = 11 kg/mt (22 lb/T) of sludge applied. See Step 1 calculation.

Second Year

N_p = 11 + (30 x 0.1) = 14 kg/mt (28 lb/T) of sludge applied.

Third Year

N_p = 11 + (30 x 0.1) + (30 x 0.05) = 15.5 kg/mt (31 lb/T) of sludge applied.

Fourth Year

N_p = 11 + (30 x 0.1) + (30 x 0.05) + (30 x 0.03) = 16.4 kg/mt (32.8 lb/T) of sludge applied.

Fifth Year

N_p = 11 + (30 x 0.1) + (30 x 0.05) + (30 x 0.03) + (30 x 0.03) = 17.3 kg/mt (34.4 lb/T) of sludge applied.

c. Step 3 - Calculate the annual quantity of sludge which can be applied to the established forest portion of the sludge application site. Assume that the plant uptake of N for the established forest remains constant at 168 kg/ha (150 lb/ac) each year.

First Year - Established Forest

Sludge application rate = $\frac{168}{11}$ = 15.3 mt/ha (6.8 T/ac)

Second Year - Established Forest

Sludge application rate = $\frac{168}{14}$ = 12 mt/ha (5.4 T/ac)

Third Year - Established Forest

Sludge application rate = $\frac{168}{15.5}$ = 10.8 mt/ha (4.8 T/ac)

Fourth Year - Established Forest

Sludge application rate = $\frac{168}{16.4}$ = 10.2 mt/ha (4.6 T/ac)

Fifth Year - Established Forest

Sludge application rate = $\frac{168}{17.3}$ = 9.7 mt/ha (4.3 T/ac)

d. Step 4 - Calculate the annual quantity of sludge which can be applied to the young plantation portion of the sludge application site. Assume that the plant N uptake for the young plantation increases each year during the 5 years because of tree growth, in the following manner:

Year	Young Plantation Plant N Uptake (kg/ha)
0-1	20
1-2	30
2-3	45
3-4	65
4-5	90

First Year - Young Plantation

Sludge application rate = $\frac{20}{11}$ = 1.8 mt/ha (0.8 T/ac)

Second Year - Young Plantation

Sludge application rate = $\frac{30}{14}$ = 2.1 mt/ha (1.0 T/ac)

Third Year - Young Plantation

Sludge application rate = $\frac{45}{15.5}$ = 2.9 mt/ha (1.3 T/ac)

Fourth Year - Young Plantation

Sludge application rate = $\frac{65}{16.4}$ = 4.0 mt/ha (1.8 T/ac)

Fifth Year - Young Plantation

Sludge application rate = $\frac{90}{17.3}$ = 5.2 mt/ha (2.3 T/ac)

e. Step 5 - Summarize the sludge application rate calculations, as follows:

Year	Established Forest (mt/ha)	Young Plantation (mt/ha)
0-1	15.3	1.8
1-2	12.0	2.1
2-3	10.8	2.9
3-4	10.2	4.0
4-5	9.7	5.2

7.6.4 Calculate the Quantity of Sludge Which Can Be Applied to the Site

The site has 1,000 ha (2,471 ac) suitable for sludge application, which is roughly equally divided between established forest and young plantation (assume 500 ha [1,235 ac] of each). The quantity of sludge which can be applied is summarized below:

Year	Established Forest (mt)	Young Plantation (mt)	Total (mt)
0-1	7,650	900	8,550
1-2	6,000	1,050	7,050
2-3	5,400	1,450	6,850
3-4	5,100	2,000	7,100
4-5	4,850	2,600	7,450

The community generates 18.2 mt/day (20 T/day), dry weight, of sludge, or 6,643 mt/year (7,307 T/year), so the hypothetical site is of sufficient area. If possible, the portion of the site area overlying the drinking water aquifer should be excluded so that the final design would not be constrained by nitrate limits. If that is not possible, then the final design should include an allowance for permissible nitrate concentrations (10 mg/l) at the project boundary, and raise the sludge loadings accordingly. The preliminary calculations above do not include this allowance.

7.6.5 Determine Cumulative Metals Loadings

Metal	kg/mt Sludge	Limits (kg/ha) (Table 6-2)
Pb	0.5	1,120
Zn	2.0	560
Cu	0.5	280
Ni	0.1	280

7.6.6 Cumulative Sludge Loadings

Example: $\text{Pb} = \frac{1{,}120\ \text{kg/ha}}{0.5\ \text{kg/mt}} = 2.240\ \text{mt/ha}$

Metal	mt Sludge/ha
Pb	2,240
Zn	280
Cu	560
Ni	2,800

Since it is a commercial forest, and there is no intention to convert to food chain crop production, the Cd limit does not apply. The Zn limit of 280 mt is adopted as a conservative control. The phytotoxic effects are not well known, but it seems likely that the forest vegetation could accept much higher levels without harm.

At 280 mt/ha, the useful design life of the sites is as follows:

Established Forest: $\frac{280\ \text{mt/ha}}{11\ \text{mt/yr}} = 25\ \text{yr}$

New Plantation: $\frac{280}{5} = 56\ \text{yr}$

7.6.7 Application Scheduling

Scheduling sludge application requires a consideration of both the soil and age of the forest. High rainfall periods and/or freezing conditions can limit sludge applications in almost all situations. Vehicle access to the steeper soils could potentially be too difficult during the wet parts of the year. All applications to the young plantations will be done during the late fall, winter, and early spring when the trees are dormant. An application schedule for a 1-year period is shown in the Table 7-6 for this design example.

It would be feasible with the schedule in Table 7-6 to avoid any need for storage. However, because adverse climatic conditions cannot be predicted, it is recommended that a 1-month (30-day) storage lagoon be constructed. Such a lagoon would hold approximately 550 dry mt (600 T). At 4 percent solids, the liquid storage capacity required would be 13.3 mil l (3.4 mil gal).

7.6.8 Sludge Application Equipment

In 1982, the City of Seattle (Municipality of Metropolitan Seattle, Washington) developed specifications for, and procurred, a specially equipped and modified sludge application vehicle for forest sludge applications (63), as shown in Figure 7-1. The vehicle is articulated, four-wheel drive, and capable of traversing a 25 percent side slope and tight turn radii. Maximum vehicle width is 2.74 m (9 ft), since 3.05-m (10-ft) tree spacings are common on timber plantations. Additional special equipment includes a 7,570-l (2,000-gal) sludge tank, a sludge cannon able to project 757 l (200 gpm) of sludge a minimum distance of 30 m (100 ft), flotation tires, and a lightweight dozer blade and winch to move stumps, fallen trees, and other obstacles which might be encountered. Vehicle cost in early 1983 was $175,000. It is assumed that vehicles similar to this would be used for the hypothetical design example.

7.7 References

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TABLE 7-6
MONTHLY APPLICATION SCHEDULE FOR A DESIGN IN THE PACIFIC NORTHWEST*

	Glacial Soil		Residual Soil	
Month	Young Plantation	Established Forest	Young Plantation	Established Forest
January	A	A	LA	LA
February	A	A	LA	LA
March	A	A	LA	LA
April	NA	A	NA	A
May	NA	A	NA	A
June	NA	A	NA	A
July	NA	A	NA	A
August	NA	A	NA	A
September	NA	A	NA	A
October	A	A	LA	LA
November	A	A	LA	LA
December	A	A	LA	LA

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[*] Abbreviations:

A = Site available, no limitations.

NA = Not available, damage will be caused by sludge on growing foliage.

LA = Limited availability, periods of extended rain are to be avoided due to vehicle access problems.

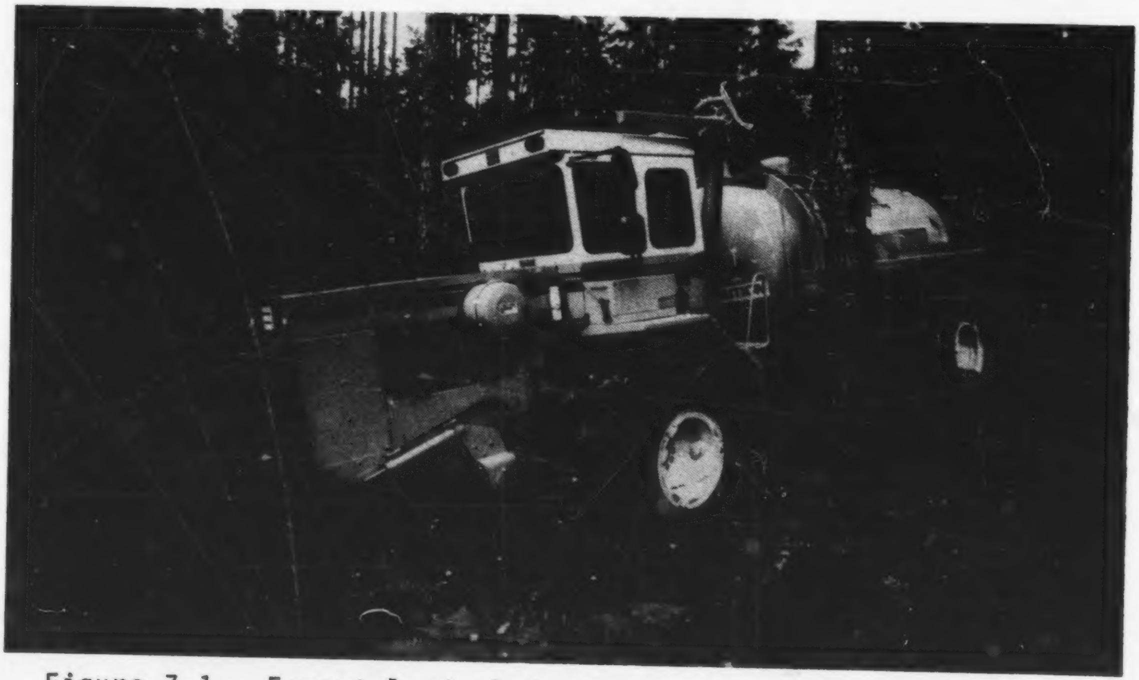

Figure 7-1. Forest land sludge application vehicle (courtesy of City of Seattle).

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CHAPTER 8

PROCESS DESIGN FOR DISTURBED LAND

8.1 GENERAL

This chapter presents design information for application of sewage sludge to disturbed land. It is assumed that the preliminary planning discussed in earlier chapters has been done, that a sludge transportation system has been selected, and that disturbed lands are potentially available within a reasonable distance from the POTW. Primary emphasis is upon the revegetation of the disturbed land site with grasses and/or trees. If future land use for agricultural production is planned, the reader should also refer to Chapter 6, "Process Design for Agricltural Utilization."

Disturbed land can result from both surface and underground mining operations, as well as the deposition of ore processing wastes. The Soil Conservation Service reported that as of July 1, 1977, the minerals industry had disturbed a total of 2.3 mil ha (5.7 mil ac), of which about 50 percent was associated with surface mining (65). Only about one-third of the disturbed area is reported to have been reclaimed.

Extensive areas of disturbed land exist throughout the United States. As a result of mining for clay, gravel, sand, stone, phosphate, coal, and other minerals. Also fairly widespread are areas where dredge spoils or fly ash have been deposited, and construction areas (e.g., roadway cuts, borrow pits) (55).

Most disturbed lands are difficult to revegetate. These sites generally provide a harsh environment for seed germination and subsequent plant growth. Major soil problems may include a lack of nutrients and organic matter, low pH, low water-holding capacity, low rates of water infiltration and permeability, poor physical properties, and the presence of toxic levels of trace metals. To correct these conditions, large applications of lime and fertilizer may be required, and organic soil amendments and/or mulches also may be necessary.

Pilot- and full-scale demonstration projects have shown that properly managed sludge application is a feasible method of reclaiming disturbed land, and can provide a cost effective option for municipal sludge disposal. Table 8-1 lists selected projects.

The sludge application is usually a one-time application, i.e., sludge is not again applied to the same land area at periodic intervals in the future. Where this is true, the project must have a continuous supply of new disturbed land upon which to apply sludge in future years. This additional disturbed land can be created by ongoing mining or mineral processing operations, or may consist of presently existing large areas of disturbed land which are gradually reclaimed. In either case, an

TABLE 8-1
SELECTED LAND RECLAMATION PROJECTS INVOLVING MUNICIPAL SLUDGES

State	Type of Disturbed Land	Type of Vegetation Used	Type of Sludge Used	References
Pennsylvania	Acidic strip-mine and deep mine refuse	Various grasses, legumes, and tree species	Dig-D,L,C	24, 31, 32, 33, 38, 54, 55, 56
Virginia	Acidic strip-mine spoil	Virginia pine and grasses and legumes	Dig-D C	24, 27, 51, 67
West Virginia	Acidic strip-mine spoil	Blueberries and tall fescue	Dig-D,C D	37, 64
Ohio	Acidic strip-mine spoil	Tall fescue and forage	Dig-D D	23, 67
Maryland	Acidic strip-mine spoil and gravel spoils	Grass, legumes, and row crops	Dig-C C	22, 28
Kentucky	Acidic strip-mine spoils	Various tree species and row crops	Dig-D	17, 52
Delaware	Dredge spoils	Various grasses	Dig-D	--
Tennessee/ South Carolina	Copper mine, borrow pit, kaolin spoil marginal land	Loblolly pine and other tree species; grasses	Dig-D	6, 12
Alabama	Stripmine spoils	Various grasses	Dig-D	--
Florida	Phosphate mining spoils	Various grasses	Dig-D	--
Illinois 26, 49,	Both acidic and calcareous stripmine spoil; coal refuse	Various grasses, legumes, and tree species; forage, row crops, and small grains	Dig-D,L D	8, 9, 18, 19, 21, 25, 29, 30, 35, 36, 45, 46, 50, 57, 58, 59, 62, 66
Michigan	Quarry spoils	Various grasses and tree species	D	--
Wisconsin	Iron ore trailings; taconite tailings	Native prairie grasses and forbes; various grasses and legumes	Dig-D	10, 40
Colorado	Molybdenum mine spoils and coal mine spoils	Grasses and native vegetation	Dig-D	--
Oklahoma	Zn smelter outfall area	Various grasses and legume	Dig-L	20

TABLE 8-1 (continued)

State	Type of Disturbed Land	Type of Vegetation Used	Type of Sludge Used	References
Montana	Surface mine spoils	Various grasses and native vegetation	C	--
New Mexico	Coal mine spoils	Various grasses	Dig-D	1
California	Clear cut forest and construction areas	Various grasses and tree species	Dig-D,C	--
Washington	Strip mine spoils, construction areas and clear cut forest	Various tree species and grasses	Dig-D	7, 11, 15

Dig = Digested
L = Liquid
D = Dewatered
C = Composted

arrangement is necessary with the land owner to allow for future sludge application throughout the life of the sludge application project.

8.2 Public Participation Considerations

Public participation aspects are discussed in Chapter 3.

8.3 Post Sludge Application Land Utilization

If sludges are used in the reclamation process there are two sets of guidelines and recommendations that should be considered. First there are federal and state mining regulations concerning revegetation under the Federal Surface Mining Control and Reclamation Act of 1977 (PL 95-87) (44, 60). Secondly, there are the federal and state guidelines and recommendations related to land application of sludge. Prior to beginning a reclamation project, the final use of the site after it has been reclaimed must be considered in relation to compliance with these regulations.

8.3.1 Mining Regulations

Prior to mining, a plan must be submitted to the appropriate agency stating the method of reclamation and post-mining land utilization. Under these regulations, the potential post-mining land use must be of a level equal to or higher than the pre-mining land use. From a mining engineer's point of view, there are five general levels of involvement for post-mining land use. They are in increasing order of beneficial use:

1. Wilderness or unimproved use.
2. Limited agriculture or recreation with little development, such as forestland, grazing, hunting, and fishing.
3. Developed agriculture or recreation, such as crop land, water sports, and vacation resorts.
4. Suburban dwellings or light commercial and industry.
5. Urban dwelling or heavy commercial and industry.

Many of these land uses are compatible with sludge application.

The post-mining use of the site must be considered when determining the sludge application rate. If the post-mining land use is to be agricultural production or animal grazing, agricultural sludge utilization practices and restrictions should be considered. If the site is to be vegetated primarily for erosion control, a single large application of sludge is desirable for rapid establishment of the vegetative cover. A majority of the reclaimed mine areas in the humid regions have been planted to forests, some of which are managed for lumber or pulp production, while others are allowed to follow natural succession patterns. If the reclaimed area is to be turned into forestland, larger sludge application rates can be considered since the products from the forest are not generally a factor in the human food chain. In all cases, postmining land use must be considered prior to the use of sludge in land reclamation.

8.4 Detailed Site Investigation

Disturbed or marginal land areas differ in their physical, hydrological and soil chemical characteristics. These differences are the result of variations in mining operations, ore extraction processes, length of time since the area was disturbed, climate, soil and geological variations, and other factors. When the land has been severely disturbed, it is often necessary to conduct relatively extensive site investigations. Available soil survey maps, topographic maps, etc. are often useless because of the changes made to the site's original characteristics.

There may be areas at a disturbed site that, due to physical, hydrological, or chemical characteristics, are unsuitable for sludge application. Areas suitable for sludge application should be surveyed and boundaries staked.

Both federal and many state mining regulations in effect in 1982 require that areas disturbed by mining operations must be restored to the approximate original contour and productivity (44). However, many older abandoned mine sites have never been reclaimed. In any case, an accurate topographic contour map of the site area is needed to provide a basis for (1) delineating the areas with slopes which are too steep for sludge application, (2) regrading the areas if this expense is cost effective, and (3) designing surface runoff water improvements, e.g., ditches, terraces, berms, etc. Table 5-2 presents general recommendations for slope limitations. The designer should consult with the appropriate regulatory agencies to determine applicable slope criteria for the site.

A secondary consideration is the future use of the site. If agricultural use is planned, slopes of less than 6 percent are desirable. If the area is to be returned to forest and/or native vegetation to prevent erosion, slopes in excess of 12 percent can be utilized, within applicable regulatory limitations.

8.4.1 Ground Water Protection

The detailed site investigation should determine the following:

- Depth to ground water, including seasonal variations.
- Quality of existing ground water.
- Present and potential future use of ground water.

- Existence of perched water.
- Direction of ground water flow.

The general regulatory philosophy is that the application of sludge to a site should not degrade useful ground water resources beyond the boundary of the sludge application site. Occasionally, it is found that ground waters adjacent to the disturbed site are already severely degraded by previous mining operations and the aquifer can be "exempted" from non-degradation regulations. Suggested depth to ground water limitations are presented in Table 5-6.

8.4.2 Disturbed Soil Sampling and Analysis

Disturbed soil sampling and analysis are necessary to:

- Establish sludge application rates, both periodic and accumulative.

- Determine amounts of supplemental fertilizer, lime, or other soil amendment required to obtain desired vegetative growth.

- Determine the infiltration and permeability characteristics of the soil.

- Determine background soil pH, metals, nutrients, etc., prior to sludge application.

A major factor in determining the chemical characteristics of the soil at a site is that standard soil sampling procedures for undisturbed and agricultural soil will not be applicable in many cases (see Appendix C). Soil survey maps will usually only provide an idea of the type of soil present prior to the disturbance. Often, the only soil profile present on a surface mined site is the mixture of soil and geologic materials. A field inspection will have to be made to determine the number and location of samples necessary to characterize the materials. The specific analyses may vary from location to location based on the state and local regulations covering both the reclamation and sludge utilization aspects.

8.4.2.1 Disturbed Soil Sampling Procedures

Disturbed sites that have had topsoil replaced can often use standard soil sampling procedures employed on agricultural fields. For abandoned sites more intensive sampling is often necessary. On either type of site, because of the extensive soil horizon mixing that occurs during the removal and replacement of the topsoil and overburden, the surface material may vary greatly within a small area.

Although the disturbed surface materials are often not soil in the generic sense, soil tests on disturbed lands have proven useful. However, soil tests on drastically disturbed sites do have some limitations which should be taken into consideration during site evaluation. Guidelines vary widely on the number of samples to be taken. Recommendations for sampling heterogeneous strip mine spoils in the eastern U.S. range from 4 to 25 individual samples per ha (1.5 to 10 per ac). It has also been suggested that one composite sample made up of a minimum of 10 subsamples for each 4 ha (10 ac) area may be adequate (3). However, many disturbed lands are not heterogeneous, and the range and distribution of characteristics of the surface material is often more important than the average composition. In general, it is recommended that material that is visibly different in color or composition should be sampled as separate units (areas) if large enough to be treated separately in the reclamation program.

8.4.2.2 Soil pH and Lime Requirements

Most grasses and legumes, along with many shrubs and deciduous trees grow best in the soil pH range from 5.5 to 7.5, and pH adjustments may be necessary.

Where sludge is to be applied to land, several states have adopted regulations which state that the soil pH must be adjusted to 6.0 or greater during the first year of initial sludge application and 6.5 during the second year (43). In addition, the soil pH of 6.5 must be maintained for two years after the final sludge application. This is recommended since trace metals are more soluble under acid conditions than neutral or alkaline conditions. If the soil pH is not maintained above 6.0, but is allowed to revert to more acid levels, some trace metals applied in the sludge may become soluble and once in solution would be available for plant uptake. In coal spoil banks, iron, aluminum, and manganese present in the spoil become mobile at low pH's and contribute to acid mine drainage problems. Phytotoxicity problems may be encountered from both the trace metals applied in the sludge and native toxic elements found in the spoil, if the spoil pH becomes highly acid. Liming recommendations can usually be obtained by sending samples to a qualified laboratory or the agricultural experiment station soil testing lab at the nearest land grant college or university. Common soil tests for lime requirements often seriously underestimate the lime requirement for sulfide-containing disturbed lands. In addition, the application of sludge on disturbed lands will cause further acidification. This must be taken into consideration in calculating lime requirements.

8.4.2.3 Cation Exchange Capacity (CEC)

Recommended limits related to the CEC of the soil (Table 6-2) have been developed for the maximum amounts of trace metals that should be applied to agricultural soils via sewage sludge additives (41). Even though a particular site will not be returned to agricultural utilization, these recommendations are often used in state requirements for disturbed land. Several states have established different limits for maximum amounts of trace metals that may be applied to the land via sludge based on the CEC of the soil.

8.4.2.4 Disturbed Soil Fertility

During mining and regrading operations, the original surface layers are usually buried so deeply that the soil nutrients present are not available to the plants in disturbed soil. Therefore, fertility of the soil is important in deciding what soil amendments are necessary to establish vegetation.

Nitrogen and phosphorus are generally deficient on disturbed lands. Sludge is generally an excellent source of these nutrients, and recommendations can be obtained from the local agricultural experiment station or Cooperative Extension Service for the additional quantity of N, P, and K required to support the vegetation planned for the site.

Phosphorus is often the most limiting fertility factor in plant establishment on drastically disturbed land (5). Soil tests used for P analysis reflect the chemistry of soils, and thus are more regionalized than tests for other major nutrients. A number of soil tests have been developed for use on acid soils in the eastern United States and others for use on neutral and calcareous soils in the west. However, drastically disturbed lands do not always reflect the local soils. Thus, if disturbed spoil material is going to be analyzed for P, the local routine analysis procedure may not be appropriate and other P analysis might be required. Recommendations should be obtained from the local agricultural experiment station.

8.4.3 Chemical Characteristics of Drainage Water

Water pollution problems, such as acid mine drainage, have been associated with mining activity. Therefore, it is necessary to document the quality of both the surface and ground water prior to use of sludge on a disturbed site. In many instances, the water quality on, and adjacent to, disturbed sites has already been adversely affected.

8.5 Constraints

When designing a sludge utilization project on drastically disturbed land, there are often two sets of criteria that must be followed. If it is an active mining site, the project should comply with the criteria set forth in Public Law 95-87 and any pertinent state regulations (5). Additionally, if sludge is to be used as a soil amendment, there are also federal and usually state guidelines and regulations that must be considered (14, 41, 43).

8.5.1 Constraints Related to Sludge Applications

8.5.1.1 Single Application Versus Annual Application

A major difference between the application of sludge to disturbed land and the other sludge land application options is that sludge is often applied to disturbed land in a one time, single large application, as compared to annual or periodic smaller applications.

Drastically disturbed lands can be divided into two categories, those requiring topsoil enhancement and those without topsoil. On sites with topsoil, an agricultural utilization rate might be used with small quantities of sludge being applied annually (discussed in Chapter 6). However, on abandoned sites or sites without topsoil replacement, a much larger application of sludge may be necessary in order to establish vegetation and improve the physical status of the soil. Soil fertility is also increased by adding sludge nitrogen and phosphorus as well as many of the micro-nutrients necessary for plant growth.

8.5.1.2 Constraints Associated with the Physical Characteristics of the Sludge

The physical characteristics of sludge are discussed in Chapter 4 and Appendix A. If liquid sludge is to be applied to mined land, it should be remembered that in some cases the infiltration rate for disturbed soils is lower than that for undisturbed soils. The solids in the liquid sludge tend to fill in the surface pores and lower the infiltration rate. After the surface is clogged, it may be necessary to temporarily halt sludge application and loosen the surface material. Soils will also regain permeability when sludge dries. Since liquid sludge can contain 90 to 99 percent water, the soils hydraulic loading capacity may often become the limiting factor when determining sludge application rates. In order to supply an adequate continuous supply of plant nutrients with liquid sludge additional applications may be necessary. Application of dewatered, dry, or composted sludge does not pose the potential soil clogging problem discussed above, since there is less water that has to infiltrate or evaporate.

8.5.2 Pathogens and Parasites

If the disturbed area to be reclaimed is to be used for agricultural production, then use of agricultural sludge guidelines should be followed. If state and federal criteria are met, the system managed properly, and the sludge treated properly, there should be minimal health risk associated with agricultural use of the reclaimed areas. See Section 6.3.1, and Appendices A and B.

Public access should be restricted for a sufficient period after sludge application to prevent public contact with viable pathogens. This period may vary from 30 days to 12 months, depending upon the extent to which the sludge has been treated for pathogen destruction.

8.5.3 Organics

If the land is to be used for agricultural purposes, see Section 6.3.3 for discussion of constraints pertinent to persistant organics. Persistent organics are generally not a concern providing that the site design and operation prevents migration of sludge constituents into drinking water supply sources.

8.5.4 Nitrogen

The amount of nitrogen needed to establish vegetation on a disturbed area is dependent on the type of vegetation to be grown and the amount of nitrogen available in the soil. The designer should have information on:

- The amount and type of nitrogen in the sludge (organic N, ammonium, and nitrates).
- The plant available nitrogen content of the existing soil, if available.
- The fertilizer nitrogen requirements of the vegetation planned for the site.

This information is utilized to determine sludge application rate so that sufficient nitrogen is applied for the vegetation, but not in excessive amounts that may cause unacceptable levels of nitrate leaching into the surrounding ground water.

The post reclamation land use should also be considered when determining the amount of nitrogen needed to supply the vegetative needs. If the vegetation grown is to be harvested and removed from the site, supplemental nitrogen applications may be needed periodically to maintain adequate productivity. If the reclaimed area is reforested or the vegetation grown is not harvested, most of the nitrogen will remain on the site and be recycled by means of leaf fall and vegetation decomposition.

An advantage of using sludge is that it is a slow-release organic nitrogen fertilizer source that will supply some nitrogen for 3 to 5 years. Most of the original nitrogen is in the organic form and therefore not immediately available for plant use until it is converted to available plant forms by mineralization. This process is discussed in Appendix B.

8.5.5 Total Metal Applications

Metal constraints depend on the future use of the reclaimed land. If the land is to be used for agricultural crops entering the human food chain the limits discussed in Section 6.3.4 and 6.3.5 apply to sludge application. If, however, the land is to be reforested or planted in vegetation not entering the human food chain, the metal accumulation is limited by potential phytoxicity to the trees and vegetation. Copper, zinc, and nickel are the elements of most concern in plant phytoxicity. If the soil pH is maintained above 6.0 to 6.5, these elements should not be taken up by the vegetation in amounts great enough to cause phytoxicity.

8.6 Vegetation Selection

8.6.1 General

Many species and varieties of plants have been shown to be valuable for use in the reclamation of drastically disturbed lands. However, each site should be considered unique, and plant species or seed mixtures to be used carefully selected. Local authorities should be consulted for recommendations of appropriate species and varieties of plant materials and establishment techniques. Revegetation suggestions for various regions of the United States are presented in this section (Tables 8-2 through 8-12). Agricultural food crops are not covered here, since they were discussed in Chapter 6.

If the aim of the reclamation effort is to establish a vegetative cover sufficient to prevent erosion, a perennial grass and legume mixture is a good crop selection. It is important to select species that are not only compatible, but also grow well when sludge is used as the fertilizer. The rationale for the selection of grass and legume seeding mixtures is that the grass species will germinate quickly and provide a complete protective cover during the first year, allowing time for the legume species to become established and develop into the final vegetative cover. The grasses will also take up a large amount of the nitrogen, preventing it from leaching into the ground water. Since legume species can fix nitrogen from the atmosphere, additional sludge nitrogen additions are often unnecessary.

Plant species to be used should be selected because of their ability to grow under droughty conditions, and their tolerance for either acid or alkaline soil material. Salt tolerance is also desirable.

If a site is to be reforested, it is still generally desirable to seed it with a mixture of grasses and legumes. The initial grass and legume cover helps to protect the site from erosion and surface runoff, and to take up the nutrients supplied by the sludge. Planting slow growing tree species is generally not recommended because they generally do not compete well with the initial herbaceous cover. Fast growing hardwoods such as hybrid poplars seem to survive and grow well because they can usually compete successfully.

8.6.2 Seeding and Mulching

Herbaceous species can be seeded by direct drill or broadcast, hydro, or aerial seeding. However, disturbed sites are often too rocky and irregular for drill seeding. Broadcast seeding is generally more desirable because the stand of vegetation produced is more natural in appearance, with a more uniform and complete cover, and effective in erosion prevention and site stabilization. Broadcasting also achieves a planting depth which is better suited to the variety of different-sized seeds usually found in mixtures of species. Aerial broadcast seeding may also be useful for large tracts. It is generally not necessary to cover the seed, since the first rainfall will normally push the seed into the loosened surface spoil and result in adequate coverage.

On sites that have good topsoil, agricultural seeding rates can be used. However, on abandoned sites, it may be necessary to apply much larger amounts of seed (54).

Mulching is generally not necessary except on specific sites. Mulches are defined as organic or inorganic materials applied to the soil surface to protect the seed, reduce erosion, modify extremes in surface spoil temperatures, and reduce evaporation. Mulching is generally advisable on steep slopes and on black anthracite refuse or fly ash banks in order to protect germinating vegetation from high surface temperatures which may be lethal to most plants. Mulching may also be required by some state regulatory agencies for specific situations. Materials used for mulching are straw, hay, peanut hulls, corn cobs, bagasse, bark, sawdust, leaves, and wood chips.

TABLE 8-2
HUMID EASTERN REGION VEGETATION

Various grasses, legumes, trees, and shrubs have been evaluated for use on disturbed lands in the
humid regions of the United States. Grass species that have shown promise for use on low pH soils
in the eastern United States include weeping lovegrass, bermudagrass varieties, tall fescue, chew-
ings fescue, switchgrass, red top, colonial bentgrass, creeping bentgrass, velvet bentgrass, deer-
tongue, big bluestem, little bluestem, and brown sedge bluestem (4).

Some of the more agriculturally important grass species adapted to better soil conditions on dis-
turbed sites include: bromegrass, timothy, orchardgrass, perinnial rye grass, Italian ryegrass,
Kentucky bluegrass, Canadian bluegrass, Reed canarygrass, Dallisgrass, bahiagrass, and in special
situations, lawn grasses including *Zoysia japonica* Steud and *Zoysia matrella*. In addition to the
common grasses, several of the cereal grains, such as rye, oats, wheat, and barley have been used,
but mainly as companion crops (4).

Legume species tested on disturbed sites in eastern United States include alfalfa, white clovers,
crimson clover, birdsfoot trefoil, lespedezas, red clover, crownvetch, and hairy vetch. Other spe-
cies that have been successfully tested include flat pea, kura clover, zigzag clover, sweet clover,
and yellow sweet clover (4).

Several grass and legume mixtures have been used successfully in Pennsylvania to revegetate drastic-
ally disturbed lands amended with municipal sludges. The primary mixture and seeding rate used for
spring and summer seeding is:

Species	Amount kg/ha
Kentucky-31 tall fescue	22
Orchardgrass	22
Birdsfoot trefoil	11
Total	55

Metric conversion factor:

1 kg/ha = 0.89 lb/ac.

TABLE 8-2 (continued)

For late summer and early fall seeding the following mixture has been used successfully:

Species	Amount kg/ha
Kentucky-31 tall fescue	11
Orchardgrass	5
Winter rye (1 bu/ac)	63
Total	79

Metric conversion factor:

1 kg/ha = 0.89 lb/ac.

This mixture has usually been sufficient to establish a vegetative cover to protect the site over the winter season. The following spring, an additional seed mixture, consisting of orchardgrass (11 kg/ ha; 9.8 lb/ ac) and birdsfoot trefoil (11 kg/ha; 9.8 lb/ac), is applied. Other seeding mixtures for spring, summer, and fall seeding are found in Ref. (48).

Several tree and shrub species have been utilized on disturbed land areas in the eastern United States. However, in general, trees and shrubs have been planted either after the soil has been stabilized with herbaceous species, like grasses and legumes, or has been planted with them. On certain drastically disturbed areas, trees may be the only logical choice of vegetation where a future monetary return is expected. They do provide long-term cover and protection with little or no additional care and maintenance. The same precautions should be exercised in selecting tree species for use on disturbed land sites as in selecting grasses and legumes. The soil acidity, plant nutrient requirements, chemical and physical properties of the soil, site topographical influences, and other environmental factors should be considered.

Common tree and shrub species grown successfully on disturbed land sites in the eastern United States include black locust, European black alder, autumm olive, white pine, scotch pine, Virginia pine, short leaf pine, red pine, Norway spruce, European and Japanese larch, and bristly locust. Other suitable hardwoods not as commonly used include yellow poplar, hybrid poplars, red oak, sycamore, river birch, maples, cottonwoods, and aspens.

TABLE 8-3
DRIER MID-WEST AND WESTERN REGION VEGETATION

A large number of plant species have been tested on disturbed lands in the Intermountain Region of the United States (6). Fewer species have been evaluated for reclamation use in the drier regions of the United States. The objective in many reclamation plantings in the drier regions is to return the area to climax vegetation. In almost every instance, the soils are not the same as before the disturbance occurred, and it would seem in many cases that species lower in the successional stage may be better adapted and more easily established on these sites. Whether a single species or a mixture is selected depends on several factors, including the planned future use of the site, the desire to have the planting blend with the surrounding vegetation, and the adaptability and compatibility of the species selected. The factors limiting the successful establishment of vegetation on disturbed areas may be different on a site being reclaimed than on adjacent undisturbed areas, where a plant species may be growing together in what appears to be a stable community. Even after the species have been selected, the proportionate amounts of seeding are not easily determined. The successful experiences of the past 40 years from seeding range mixtures and planting critical areas appears to be the best guide to the opportunities for success of either single species or mixtures (5).

TABLE 8-4
WESTERN GREAT LAKES

This region includes Wisconsin, eastern Minnesota, and the western upper peninsula of Michigan. The common grasses, generally used in mixtures with a legume, are tall fescue, smooth brome, and timothy. Kentucky bluegrass and orchardgrass are also well adapted. "Garrison" creeping foxtail and reed canarygrass perform well on wet sites. The most commonly used legumes are birdsfoot trefoil and crownvetch. Numerous species of woody plants can be used depending on specific site conditions. Siberian crabapple, several species of poplars, tatarian and Amur honeysuckles, silky dogwood, red-osier dogwood, European black alder, black cherry, and green ash perform well. Autumn olive is adapted to the southern portion of this area.

TABLE 8-5
NORTHERN AND CENTRAL PRAIRIES

This is the region known as the Corn Belt.. Grasses adapted to the area are Kentucky bluegrass, tall fescue, smooth brome, timothy, and orchardgrass. Reed canarygrass is adapted to wet areas. Switchgrass, big bluestem, and Indiangrass are well adapted warm season natives. Birdsfoot trefoil, crownvetch, and alfalfa are commonly used legumes.

Woody species that have been successful include autumnolive, European black alder, poplar species, tatarian honeysuckle, Amur honeysuckle, black cherry, eastern red cedar, pines, oaks, black walnut, green ash, black locust, black haw, and osage-orange.

TABLE 8-6
NORTHERN GREAT PLAINS

This region includes most of the Dakotas and Nebraska west to the foothills of the Rocky Mountains and includes northeastern Colorado. The native wheatgrass (western, thickspike, bluebunch, streambank, and slender) are used extensively in seeding mixtures. Western wheatgrass should be included in most mixtures, although for special purposes thickspike or streambank wheatgrass are more appropriate. Green needlegrass is an important component of mixtures except in the drier areas. On favorable sites big bluestem, little bluestem, and switchgrass provide opportunities for color or for a different season of use. Prairie sandreed is adapted to sandy soils throughout the region. "Garrison" creeping foxtail and reed canarygrass are adapted to wet sites.

Crested wheatgrass has been used extensively and is long-lived in this climate. Intermediate and pubescent wheatgrasses are useful in establishing pastures. The use of smooth brome and tass fescue is limited to the eastern portions of the Northern Great Plains where the annual precipitation exceeds 50 cm (19.7 in). Alfalfa and white sweetclover are the only legumes used in most of the area for reclamation plantings.

Many native and introduced woody plants are adapted for conservation plantings. Fallowing to provide additional moisture is required for establishment of most woody plants and cultivation must generally be continued for satisfactory performance of all but a few native shrubs. These practices may not be compatible with certain reclamation objectives, thereby limiting the use of woody species to areas with favorable moisture situations. Some woody plants useful in this area, if moisture and management are provided, are Russian-olive, green ash, skunkbush sumac, Siberian crabapple, Manchurian crabapple, silver buffaloberry, tatarian honeysuckle, chokecherry, Siberian peashrub, Rocky Mountain juniper, and willow species.

TABLE 8-7
SOUTHERN GREAT PLAINS

The Southern Great Plains are considered to be the area from southcentral Nebraska and southeastern Colorado to central Texas. The most common native grasses of value in reclaiming drastically disturbed lands include big bluestem, little bluestem, Indiangrass, switchgrass, buffalograss, blue grama, sideoats grama, and sand lovegrass. Introduced bluestems such as yellow bluestem, Caucasian bluestem, and introduced Kleingrass, blue panicgrass, and buffelgrass are important in the southern and central portions of this plant growth region. Alfalfa and white sweetclover are the most commonly used legumes. Russian-olive is a satisfactory woody species in the northern portions and along the foothills of the Rocky Mountains. Junipers, hackberry, and skunkbush sumac are important native species. Osage-orange is well adapted to the eastern part of this area. Desirable woody plants require special management for use on most drastically disturbed lands.

TABLE 8-8
SOUTHERN PLAINS

This area is the Rio Grande Plains of south and southwest Texas. The characteristic grasses on sandy soils are seacoast bluestem, two-flow trichloris, silver bluestem, big sandbur, and tanglehead. The dominant grasses on clay and clay loams are silver bluestem, Arizona cottontop, buffalograss, curlymesquite, and grama grasses. Indiangrass, switchgrass, seacoast bluestem, and crinkleawn are common in the oak savannahs.

Old World bluestems, such as yellow and Caucasian bluestems, are satisfactory only where additional moisture is made available. Natalgrass and two-flower trichloris have shown promise in reclamation plantings.

TABLE 8-9
SOUTHERN PLATEAUS

The area is made up of the 750- to 2,400-m (2,450- to 7,875-ft) altitude plateaus of western Texas, New Mexico, and Arizona. The area includes a large variety of ecological conditions resulting in many plant associations. Creosote-tarbush desert shrub, grama grassland, yucca and juniper savannahs, pinyon pine, oak, and some ponderosa pine associations occur. Little bluestem, sideoats grama, green sprangletop, Arizona cottontop, bush muhly, plains bristlegrass, vine-mesquite, blue grama, black grama, and many other species are common and are useful in reclamation plantings, depending on the site conditions and elevation.

TABLE 8-10
INTERMOUNTAIN DESERTIC BASINS

This region occupies the extensive intermountain basins from southern Nevada and Utah, north through Washington, and includes the basin areas of Wyoming. The natural vegetation ranges from almost pure stands of short grasses to desert shrub. There are extensive area dominated by big sagebrush or other sagebrush species.

A wide variety of species of grasses is available for this area. Among the most commonly used species are the introduced Siberian wheatgrass, crested wheatgrass, intermediate wheatgrass, pubescent wheatgrass, tall wheatgrass, and hard fescue. Native grasses used include bluebunch wheatgrass, beardless wheatgrass, big bluegrass, Idaho fescue, and Indian ricegrass. Four-wing and Nuttall saltbush have performed well in planting trials. Available woody species are limited, though junipers, Russian-olive, skunkbush sumac, and other native and introduced woody plants are adapted to the climate where moisture is adequate.

TABLE 8-11
DESERT SOUTHWEST

This is the desert of southwestern Arizona, southern Nevada, and southern California. Creosotebush may occur in almost pure stands or with tarbush. Triangle bur-sage, white bur-sage, rubber rabbitbrush, and ocotillo are prominent on some sites. Large numbers of annual and perennial forbs are present. Saltbushes, winterfat, and spiny hopsage are common. The few grasses present in the understory are largely big galleta, desert saltgrass, grama grasses, and species of threeawns.

Only minor success has been obtained in establishing vegetation on disturbed lands in the desert southwest. Irrigation for establishment may be essential in some areas, and the longevity of stands when irrigation is discontinued is not known. Big galleta and bush muhly show promise. Native shrubs such as creosotebush, fourwing saltbush, and catclaw have also been established. Reseeding annuals such as goldfields, California poppy, and Indianwheat have also shown promise.

TABLE 8-12
CALIFORNIA VALLEYS

The climate of the central California Valleys is classified as semiarid to arid and warm and the moisture is deficient at all seasons. The largest area of grassland lies around the edge of the central valley and is dominated by annual species. The only areas remaining in grass in the valley are usually too alkaline for crop production. The grasses remaining in these sites are desert saltgrass and alkali sacaton.

Recommended for seeding in the area of more than 40 cm (15.8 in) annual precipitation is a mixture of "Luna" pubescent wheatgrass, "Palestine" orchardgrass, and rose clover. Crimson clover, California poppy, and "Blando" brome can be added.

Inland in the 30 cm (12 in) precipitation areas, a mixture of "Blando" brome, Wimmera ryegrass, and "Lana" woolypod vetch is recommended. In the 15- to 30-cm (6 to 12 in) precipitation zone "Blando" brome (soft chess) and rose clover are generally used.

8.7 Sludge Application Rates

8.7.1 General

Determining sludge application rates for reclaiming disturbed lands often presents a conflict for the designer. When sludge is applied only once, as is the case with reclamation of most drastically disturbed lands, the many important limiting factor is usually the addition of potentially toxic heavy metals. With a one-time sludge application, the goal is to create a large pool of nutrients to supply the vegetation for more than one year so that additional fertilizer amendments are not needed. This makes it necessary to exceed the annual nitrogen requirement of the vegetation, and potentially results in nitrate movement to ground water. The designer may seek a temporary exemption for the nitrogen limits from the applicable regulatory agency, because:

- The large one-time sludge application is necessary to provide a pool of nutrients to ensure future vegetation growth on the disturbed land site. Without the large sludge application, vegetation may not sufficiently establish itself, resulting in future erosion and surface water pollution. The large application also provides organic matter which improves the long-term fertility of the soil.

- The potential for nitrate degradation of ground water is slight because of favorable hydrogeological conditions at the site (great depth to ground water, intervening impermeable soil layers, high evaporation compared to precipitation rates, high dilution in the aquifer, non-drinking water aquifer, etc.).

- If commercial fertilizers are used instead the potential for ground water degradation may be greater than if sludge were used. Sludge is a slow release fertilizer because the organic nitrogen is mineralized over many years (see Appendix B).

If approved, the one-time sludge application rate is then based upon total metal loadings. If nitrogen controls, however, then the procedures in Chapter 6 or 7 apply for calculation of sludge application rates.

8.7.2 Calculation of Sludge Application Rate Based on Metal Loading

To make a one-time sludge application rate calculation based on metal loadings the designer needs the following information:

- Current cumulative metal loading limits applicable to the site. Although the limits shown in Table 6-2 are used in this example, it is possible that different limits will be applicable at the location and time the designer is making his calculations.

- The cation exchange capacity (CEC) (see Table 6-2) and pH of the soil, which should be made 6.5 or higher through lime addition, if necessary.

- The metal analysis of the sludge for Pb, Zn, Cu, Ni, and Cd.

With the above information, and using Table 6-2 as an example of the assumed total metal limits, a calculation of loading rate is made for each metal:

$$\text{Metric tons sludge/ha} = \frac{\text{kg metal allowed/ha (Table 6-2)}}{\text{mg metal/kg in sludge} \times 0.001}$$

$$\text{Tons sludge/ac} = \frac{\text{lb metal allowed/ac (Table 6-2)}}{\text{mg metal/kg in sludge} \times 0.001} \times 0.4$$

The lowest value generated from the five calculations (Pb, Zn, Cu, Ni, or Cd) determines the maximum one-time sludge application rate based on metal loadings. The design example in this chapter provides example calculations.

8.8 Monitoring Requirements

8.8.1 General

In order to comply with state, local, and federal requirements for land application of sludge, both the sludge to be utilized and the site characteristics must be evaluated. If the land application system complies with applicable criteria, it can generally be assumed that the sludge will pose little probability for adverse effects on the environment and minimal monitoring should be necessary. However, some states require additional site monitoring after the sludge has been applied.

8.8.2 Suggested Minimal Monitoring Program

8.8.2.1 Background Sampling (Pre-Sludge Application)

Composite soil samples should be collected from the site for the determination of pH, liming requirements, CEC, available nutrients and trace metals prior to sludge addition. Water samples from surface streams, lakes, etc., and private household wells in the area should be analyzed for nutrients and trace metals prior to sludge application. Composite sludge samples should be collected and analyzed to provide data for use in designing loading rates.

8.8.2.2 Sampling During Sludge Applicable

As the sludge is delivered, grab samples should be taken and analyzed for moisture content to adjust the delivered amount of sludge to the design rate if there is variation in the sludge moisture content. Composite sludge samples should be collected as the sludge is applied, to document the actual nutrient and trace metal application rate.

8.8.2.3 Post-Sludge Application Monitoring

Monitoring of the sludge application site after sludge has been applied can vary from none to extensive, depending on state and local regulations and site-specific conditions. Generally, it is desirable to analyze the soil after 1 year for soil pH changes and heavy metals (if required). In addition, surface and ground water analysis for nitrogen forms and trace metals may be needed.

Some states have very specific requirements for monitoring, so the designer should consult the appropriate regulatory agency. Monitoring requirements by the State of Pennsylvania are given (43), as an example:

The monitoring system for each contiguous parcel (up to 40 ha; 100 ac) of land to receive sludge consists of one down-gradient ground water well and on-site lysimeters. The well location is selected after the ground water flow pattern is determined. Lysimeters are installed at four locations selected to be representative of overall site conditions. Two lysimeters are installed at each location. Lysimeters are installed to collect soil percolate water at the 90 cm (36 in) depth. It is desirable to have a minimum of three samples from each site for statistical evaluation. The fourth installation is a safeguard. Wells of nearby private homes are sampled periodically before and after sludge is applied. Large diverse sites (over 40 ha; 100 ac) are subdivided into smaller parcels for monitoring purposes. Sets of lysimeters (4 stations) are installed in each parcel.

Table 8-13 is a minimum list of parameters that should be included in the routine analysis of water, soils, and vegetation. Additional parameters may be included in the analyses if specified on a case-by-case basis (43).

TABLE 8-13
WATER SAMPLE COLLECTION

1. A minimum of three samples are collected from each ground water well and lysimeter station prior to sludge application on the site.
2. After sludge application, water samples are collected monthly for a period of 1 year.
3. Samples collected prior to sludge application and for the first 3 months following sludge application are analyzed for pH, Cl, NO_3-N, NH_4-N, Org-N, Fe, Al, Mn, Cu, Cr, Co, Pb, Cd, Ni, Zn, and fecal coliforms.
4. Water samples collected during the 4th month to the 11th month following sludge application are analyzed only for pH, nitrogen forms (NH_4-N, NO_3-N), trace metals (Zn, Cu, Pb, Co, Ni, Cd, Cr), and fecal coliforms.
5. Water samples collected during the 12th month following sludge application are analyzed for constituents listed in No. 3, above.
6. Water sampling is terminated after one year unless results of the third quarterly report indicate a need to continue sampling. If further sampling is required, samples are collected quarterly until sufficient data are collected to formulate a conclusion on the problem.
7. The monitoring well is maintained past the initial year of sampling to allow for the collection of samples at a later date, if deemed necessary.

Soil Sample Collection

1. Soil samples are collected on the site prior to sludge application. Surface soil samples of the topsoil material are collected throughout the site and analyzed for buffer pH to determine lime requirements to raise the soil pH to 6.5 and to determine the cation exchange capacity. Samples from the complete soil profile are collected from the pits excavated to install the lysimeters. Soil samples are collected from the 0 to 15 (0 to 6 in), 15 to 30 (6 to 12 in), 30 to 60 (12 to 24 in), and 60 to 90 cm (24 to 36 in) soil depth.
2. Soil samples are again collected one year following sludge application. Samples are collected at the 0 to 15 (0 to 6 in), 15 to 30 6 to 12 in), and 30 to 60 cm (12 to 24 in) depth.
3. All soil samples are analyzed for pH, Bray P, Ca, Mg, K, Na, Fe, Al, Mn, Cu, Zn, Cr, Co, Pb, Cd, Ni, and Kjeldahl nitrogen.
4. At the end of the second year after sludge application, surface soil samples are collected and analyzed for pH to determine if it is still at pH 6.5.

TABLE 8-13 (continued)

Vegetation Sampling

1. Vegetation samples are collected for foliar analyses at the end of the first growing season following sludge application. Separate samples are collected for each of the seeded species. All samples are analyazed for N, P, K, Ca, Mg, Fe, Al, Mn, Cu, Zn, Cr, Co, Pb, Cd, and Ni.
2. For sites seeded in the fall, vegetation samples are collected at the end of the following growing season.

8.9 Sludge Application Methods and Scheduling

8.9.1 Transportation

Chapter 10 of this manual discusses sludge transport in detail. A special consideration in transport of sludge to reclaim mined land is that the potential may exist to backhaul sludge, i.e., to use the same trucks, railcars, etc., which transport the mined ore to the city for transport of the sludge from the city back to the mining area. For example, in 1981-82, the city of Philadelphia backhauled about 54,432 mt (60,000 T) of sludge annually in coal trucks a distance of 450 km (280 mi) to help reclaim strip mine sites in western Pennsylvania (56).

8.9.2 Site Preparation Prior to Sludge Application

Under federal and state mining regulations, the disturbed mine sites generally must be graded after mining to the approximate original contour of the area. Abandoned areas where no regrading has been done, should also be regraded to a relatively uniform, slope of less than 15 percent prior to sludge application.

8.9.2.1 Scarification

Prior to sludge application, the surface should be roughened or loosened to offset the compaction caused during the leveling or grading operation. This will help to improve the surface water infiltration and permeability, and slow the movement of any surface runoff and erosion. A heavy mining disk or chisel plow is typically necessary to roughen the surface. It is advisable that this be done along contour.

8.9.2.2 Erosion and Surface Runoff Control Measures

Surface runoff and soil erosion from the sludge application site should be contolled. These measures may include erosion control blankets, filter fences, straw bales, and mulch. It may be necessary to construct diversion terraces and/or sedimentation ponds. The local Soil Conservation Service can be contacted to aid in the design of the erosion and surface runoff control plans. In addition, see Chapter 10 of this manual.

8.9.3 Methods of Application

Methods of sludge application to land are discussed in Chapter 10.

8.9.4 Scheduling

The timing of sludge application depends on the climate, soil conditions, and growing season. It is generally not advisable to apply sludge to frozen or snow-covered ground, since it cannot be immediately incorporated and seeded. If the sludge is applied to frozen or snow covered ground and allowed to remain on a sloped surface, the chances of surface runoff are increased as the snow melts or if a heavy rain storm occurs. The sludge should not be applied during periods of heavy rainfall since this greatly increases the chances of surface runoff. Sludge should not be applied in periods of prolonged extreme heat or dry conditions, since considerable amounts of nitrogen will be lost before the vegetation has a chance to establish itself. If sludges are applied and allowed to dry on the soil surface, from 20 to 70 percent of the NH_4-N will be volatilized and lost to the atmosphere as NH_3. The exact amount of NH_4-N lost will depend on soil, sludge, and climate conditions (53).

Sludge applications should be scheduled to accommodate the growing season of the selected plant species. If the soil conditions are too wet when sludge is applied, the soil structure may be damaged, bulk density increased, and infiltration decreased due to heavy vehicle traffic on the wet soil. This may increase the possibility of soil erosion and surface runoff. Also the tractors or trucks may experience difficulty driving on the wet soil.

If the area to receive sludge is covered under federal or state mining regulations, the sludge application must be scheduled to comply with the revegetation regulations. For example, in Pennslvania mined land can be seeded in the spring as soon as the ground is workable, usually early in March, but seeding must terminate by May 15. Late summer seeding season is from August 1 until September 15. In Pennsylvania, sludge application and seeding of mined land covered by these regulations must comply with these requirements. The designer should check on requirements for his locale.

8.9.4.1 Storage

Some need for sludge storage will be likely. It may be either at the treatment plant and/or at the application site. In general, when liquid sludge is used, storage is provided at the treatment plant in digesters, holding tanks, or lagoons. At application sites where large quantities of sludge are utilized, storage lagoons may be built at the utilization site.

If dewatered sludge is used, storage may be more advantageously stored at the application site. Small storage areas are desirable at the treatment plant for times of inclement weather or equipment breakdown.

At currently mined sites, it may be necessary to transport and stockpile dewatered sludge at the site while the area is being backfilled and topsoiled. This would allow large quantities of sludge to be applied in a relatively short period of time. Stockpiling of sludge at the site prior to application would allow for more efficient utilization of manpower and equipment for spreading large quantities of sludge in a short period of time. Some states have specific regulations concerning sludge stockpiling on the site for short periods of time. For example, in Pennsylvania, the sludge storage area must be diked to prevent surface water from running into or out of the storage area.

8.9.4.2 Other Conditions

Some states have included various conditions that must be met in order to be granted a permit to apply sludge to disturbed land. For example, some states do not allow sludge to be utilized for the revegetation of inactive mines or active coal refuse piles on slopes exceeding 15 percent. Dairy cattle may not be allowed to graze the land for at least two months after sludge application. Many states have regulations concerning buffer areas where sludge cannot be applied. Pennsylvania requires that sludge cannot be applied within 30 m (98 ft) of streams, 90 m (300 ft) of water supplies, 8 m (26 ft) of bedrock outcrop, 15 m (50 ft) of property lines, or 90 m (300 ft) of occupied dwellings. In addition to sludge management regulations, if the site is an actively mined area, all mining regulations concerning revegetation must also be considered in the design of the sludge utilization project.

8.10 Design Example for Sludge Application to Disturbed Land

It is intended to reclaim on a trial basis a portion of a drastically disturbed areas with a one-time application of sludge. The single large application should provide organic matter and nutients required to support establishment of a mixture of grass and legumes. The site may in the future be used for agricultural purposes, so the cumulative (total) metal loadings are a design concern. The state regulatory agency is aware that the one-time heavy application of sludge may result in temporary leaching of excess nitrates to the ground water, and requires monitoring to quantify the impact.

8.10.1 Sludge Characteristics

The sludge to be applied is an anaerobically digested, dewatered sludge with an average analysis on a dry weight basis, as follows:

Solids - 54%
Total N - 1.5%
NH_4-N - 0.6%
Total P - 0.5%
Total K - 0.1%

Pb - 500 mg/kg
Zn - 2,000 mg/kg
Cu - 500 mg/kg
Ni - 100 mg/kg
Cd - 50 mg/kg

8.10.2 Site Characteristics

Location: Mid-Atlantic State
Area: 2 ha (5 ac)
Soil pH: 3.9
Soil CEC: 13 meq/100 g
Soil Permeability: 0.2 cm/hr
Depth to Ground Water: 5 m (16 ft)
Annual Precipitation: 80 cm (31.5 in)

8.10.3 Calculation of Maximum Sludge Application Rate Based on Metal Loadings

Table 6-2 presents suggested cumulative limits for metals applied to agricultural cropland as a function of soil CEQ. For convenience, these suggested limits are repeated below for soil CEQ in the range 5-15 meq/100 g, typical of the design site soil:

Pb - 1,120 kg/ha (1,000 lb/ac)
Zn - 560 kg/ha (500 lb/ac
Cu - 280 kg/ha (250 lb/ac)
Ni - 280 kg/ha (250 lb/ac)
Cd - 10 kg/ha (8.9 lb/ac)

Combining the above metal loading limits with the sludge characteristics in the equation below allows determination of the maximum loading for the limiting metal:

$$\text{mt sludge/ha} = \frac{\text{kg/ha metal allowed}}{(0.001)\ (\text{mg/kg metal in sludge})}$$

For zinc:

$$\text{mt sludge/ha} = \frac{560\ \text{kg/ha}}{(0.001)\ (2{,}000\ \text{mg/kg})} = 280\ \text{mt/ha}$$

Using similar calculations, the loading limits for all of the metals are as follows:

	Maximum Sludge Application Rate	
Metal	Mt/Ha	T/Ac
Pb	2,240	999
Zn	280	125
Cu	560	250
Ni	2,800	1,250
Cd	200	89

Cadmium is the limiting metal in this case, allowing a maximum sludge application of 200 mt/ha (89 T/ac).

8.10.4 Lime Application Determination

Based upon appropriate soils tests, it was determined that agricultural lime application of 12.3 mt/ha (5.5 T/ac) is sufficient to raise the soil pH to 6.5.

8.10.5 Calculation of Nutrient Application

The nutrient content of the 200 mt/ha (89 T/ac) of sludge applied is calculated as follows:

Nutrient Applied in kg/ha = % Nutrient in Sludge x Application Rate x 10

Using a similar calculations for the other nutrients:

Total N = 3,000 kg/ha (2,670 lb/ac)
NH_4-N = 1,200 kg/ha (1,068 lb/ac)
Organic N = 3,000-1,200 = 1,800 kg/ha (1,602 lb/ac)
Total P = 1,000 kg/ha (890 lb/ac)
Total K = 200 kg/ha (178 lb/ac)

8.10.5.1 Calculation of Potential Nitrate Leaching into the Ground Water

It is possible to make a conservative estimate of the quantity of nitrates potentially leaching into the ground water by (1) calculating the available nitrogen added by the sludge application, (2) subtracting the estimated nitrogen uptake by the vegetation and other nitrogen losses, and (3) calculating the maximum potential concentration of excess nitrates percolating from the site into the underlying aquifer.

Step 1 is to calculate the available nitrogen in the first year and succeeding years from a one-time sludge application of 200 mt/ha (89 T/ac):

NH_4-N applied = 1,200 kg/ha (1,068 lb/ac)
Organic N applied = 1,800 kg/ha (1,602 lb/ac)

All of the NH_4-N applied is assumed to be available in the first year. As discussed in Section 6.4.3.1, a fraction (percentage) of the organic nitrogen applied mineralizes during the first year after sludge application, and each year thereafter. Referring to Table 6-7, it is assumed for this design example that the organic N mineralization rates are: first year - 20%; second year - 10%; third year - 5%; succeeding years - 3% each year.

Experience with wastewater irrigation indicates that about 10 to 15% of the nitrogen available is lost by unaccounted for means (13). The pathways suggested are volatilization and denitrification. It is conservative to assume that similar unaccounted for losses of 10% will occur with incorporated sludges applied on a one-time basis, since the mineralization of organic N will make ammonia-N available for volatilization or nitrification. This nitrogen reduction applies only to the inorganic nitrogen fraction in the sludge/soil mixture mixture, and should not be taken if specific reductions for volatilization and/or denitrification have previosuly been deducted.

First Year Calculation:

NH_4-N 1,200 kg/ha	
Organic N (1,800 kg/ha) x 20% mineralization rate	360 kg/ha
Subtotal	1,560 kg/ha
Deduct for unaccountable losses (10%)	(156) kg/ha
Deduct for vegetation uptake	(300) kg/ha
Total excess available N in the first year	1,104 kg/ha (983 lb/ac)

Second Year Calculation:

NH_4-N 0 kg/ha	
Organic N remaining (1,440 kg/ha) x 10% mineralization rate	144 kg/ha
Subtotal	144 kg/ha
Deduct for unaccountable losses (10%)	(14) kg/ha
Deduct for vegetation uptake	(300) kg/ha
Total excess available N in the second year	-170 kg/ha

(There is a deficit, not an excess in the second year)

Ground water contamination from leaching of excess available nitrogen is only a concern during the first year after sludge application. A very conservative estimate can be made of the concentration of nitrates in the percolate from the site during the first year. This calculation assumes that all of the excess nitrogen is converted to nitrates, and there is no dilution of percolate by existing ground water.

Assume 80 cm annual net precipitation.
Assume 12% evaporation losses.

If all of the excess nitrogen in the sludge applied is mobile (an unlikely and very conservative assumption), the concentration of nitrate in the percolate is calculated below:

$$\frac{(1{,}104 \text{ kg/ha})\ (10^6 \text{ mg/kg})\ (1{,}000 \text{ cm}^3\text{/l})}{(10^8 \text{ cm}^2\text{/ha})\ (80 \text{ cm})\ (0.80)} = 172 \text{ mg/l}$$

A potential concentration of 172 mg/l of nitrate nitrogen in the percolate from the site during the first year after sludge application may be unacceptable to the regulatory agency, even though the contamination is a temporary 1-year effect, and there is no extraction of potable water from the aquifer.

8.10.5.2 Recalculation of Sludge Application Rate Based on Percolate Nitrate Concentration

Assuming that the regulatory agency allows no higher than 10 mg/l of nitrate concentration in the percolate from the site, the maximum excess available nitrogen application rate which will achieve this limit can be calculated:

$$\text{Max. Excess Avail. N} =$$

$$\frac{(10 \text{ mg/l})\ (10^3 \text{ cm}^2\text{/ha})\ (80 \text{ cm})\ (0.80)}{(10^6 \text{ mg/ha})\ (1{,}000 \text{ cm}^3\text{/l})} = 64 \text{ kg/ha}$$

Maximum allowable excess N (from above calculation)	64 kg/ha
Vegetation nitrogen uptake (determined previously)	300 kg/ha
Subtotal	364 kg/ha
Unaccountable nitrogen losses (assumed previously)	36 kg/ha
Total allowable available N application	400 kg/ha (365 lb/ac)

The sludge application rate corresponding to application of 400 kg/ha (356 lb/ac) of available nitrogen is calculated using the following equation:

$$\text{Mt Sludge/Ha} = \frac{(\text{kg/ha of available nitrogen allowed})\ (0.10)}{(\%\ NH_4\text{-}N)\ (1.0) + (\%\ \text{organic N})\ (0.20)}$$

$$= \frac{(400 \text{ kg/ha})\ (0.10)}{(0.6)\ (1.0) + (0.9)\ (0.20)} = 51 \text{ mt/ha } (23 \text{ T/ac})$$

As previously noted, the above calculation procedure results in a very conservative sludge application rate. See the Venango, Pennsylvania, case study in Appendix D for first year and long-term nitrate measurements in the ground water at an actual site similar to that used for this design example.

8.11 References

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CHAPTER 9

PROCESS DESIGN FOR SLUDGE APPLICATION TO LANDS DEDICATED FOR DISPOSAL

9.1 General

A DLD project has the following general characteristics:

1. The primary purpose of the site is long-term sludge application, i.e., it is a dedicated disposal site for land spreading of sludge. Any additional site activities or benefits, such as growing of agricultural crops or improvement of soil characteristics, are secondary to the primary sludge application activity.

2. Typically, sludge application rates are substantially higher than used for the agriculture, forest and disturbed land options discussed in previous chapters. There may be some overlap, however, in specific cases, especially where crops are grown on the site. Higher application rates reduce the area of land required and may also simplify sludge distribution.

3. Typically, the agency which is implementing the project owns the site, or has a long-term lease which allows the agency substantial discretion in use of the land for sludge spreading purposes.

4. The site is more carefully designed, managed, and monitored than are sites using other options.

5. Site design and operations are focused upon containing within the site any environmentally detrimental sludge constituents. Surface runoff, ground water leachate, and harvested crops (if any) are controlled to prevent adverse effects. Regulatory agency limits and controls are virtually always required, and permitting procedures often involve many governmental agencies.

Sludge for DLD site application should be stabilized to minimize odors, vector breeding, and pathogen transmission. Once stabilized, sludge can be applied to the dedicated site either in liquid or dewatered form.

This chapter discusses the DLD process design, and includes regulatory considerations, site investigation, determination of application rates, site preparation, application methods, monitoring needs, and site closure. A design example is provided at the end of the chapter. Most of the discussion pertains to sites where the sludge application rates greatly exceed agricultural utilization rates.

9.2 Regulatory Considerations

Regulations pertinent to sludge application to land are detailed in Chapter 4, Section 4.3.

Usually, the use of land as a DLD must be recorded in the property deed so future owners will know that the site soil characteristics have been altered. This should be checked with the appropriate local authorities agency.

A number of regulatory agencies may be involved in the site approval and permitting process. As an example, Table 9-1 lists eight agencies which were involved in permit approvals prior to construction of a DLD project at Sacramento, California. A typical DLD project requires substantial interaction with many agencies, and the designer must keep appraised of all applicable regulations through early coordination with agency staffs.

TABLE 9-1
PERMITS AND APPROVALS NEEDED PRIOR TO CONSTRUCTION OF A DLD PROJECT AT SACRAMENTO, CALIFORNIA (1)

Agency	Approval
California Regional Water Quality Control Board, Central Valley Region	Waste discharge requirements
State Department of Water Resources	Dam safety permits may be required depending upon sludge storage pond volume above grade
U.S. Army Corps of Engineers	Section 404 permits for filling wetlands
State Department of Fish and Game	Stream alteration permit and filling of wetlands
State Solid Waste Management Board	County Solid Waste Management plan amendment
County Division of Water Resources	Approval for modifications to floodplain
County Water Agency	Approval for drainage modifications
County Planning Department	Special use permit prior to construction

9.3 Public Participation

The principals of public participation programs for sludge to land projects are detailed in Chapter 3. Virtually all proposed DLD projects will undergo an extensive public participation process, and the project proponents should show that the DLD option is the most suitable in terms of economics, technical feasibility, and environmental impact.

9.4 Basic Types of Dedicated Land Disposal Site Designs

Figure 9-1 shows the basic alternatives for consideration in DLD site design. A brief description of each alternative is provided below:

Alternative 1 - All surface water runoff is contained within the site through use of dikes, lagoons, etc., and disposed through evaporation.

- All ground water leachate is contained beneath the site due to natural impervious geological barrier (e.g., impervious clay, bedrock, etc.) between the site and useful aquifers. In some site specific cases, the aquifers potentially affected by the site may already contain useless water and protection of these aquifers is of no concern.
- Sludge liquid removal is entirely by evaporation.
- Sludge constituent removal is by utilization, bacterial activity, and chemical/physical reactions with the soil.
- Sludge constituents not removed by the above mechanics accumulate in the soil profile.

Alternative 2 - Same as 1 above, except crops (e.g., grasses, clover, etc.) are planted to enhance moisture removal through evapotranspiration. The crops, in addition, remove a portion of many sludge nutrients and other constituents through plant uptake mechanisms. Harvesting, removal, and controlled use or disposal of crops can remove from the site those sludge constituents incorporated into the crops.

Alternative 3 - Same as 1 or 2 above, except provision is made for controlled discharge of surface runoff off-site. Controlled discharge is achieved by adequate storage, treatment if necessary, monitoring, and other requirements of the NPDES permitting procedure. In some cases, it may be feasible to provide a controlled discharge back into the sewage treatment system.

Alternative 4 - Same as 1, 2, or 3 above, except that ground water leachate is intercepted and not allowed to percolate to ground water aquifers. Interception mechanisms are usually subsurface drain tiles. Under favorable geological conditions, interceptor ditches, well point systems, deep well pumping, or other ground water interception systems may also be feasible. In any case, the intercepted leachate is collected, stored, treated (if necessary), and removed. Leachate removal may be through evaporation, or discharge to a sewage treatment system. With adequate treatment the collected leachate may be used to irrigate site vegetation or discharged into surface waters under NPDES permit.

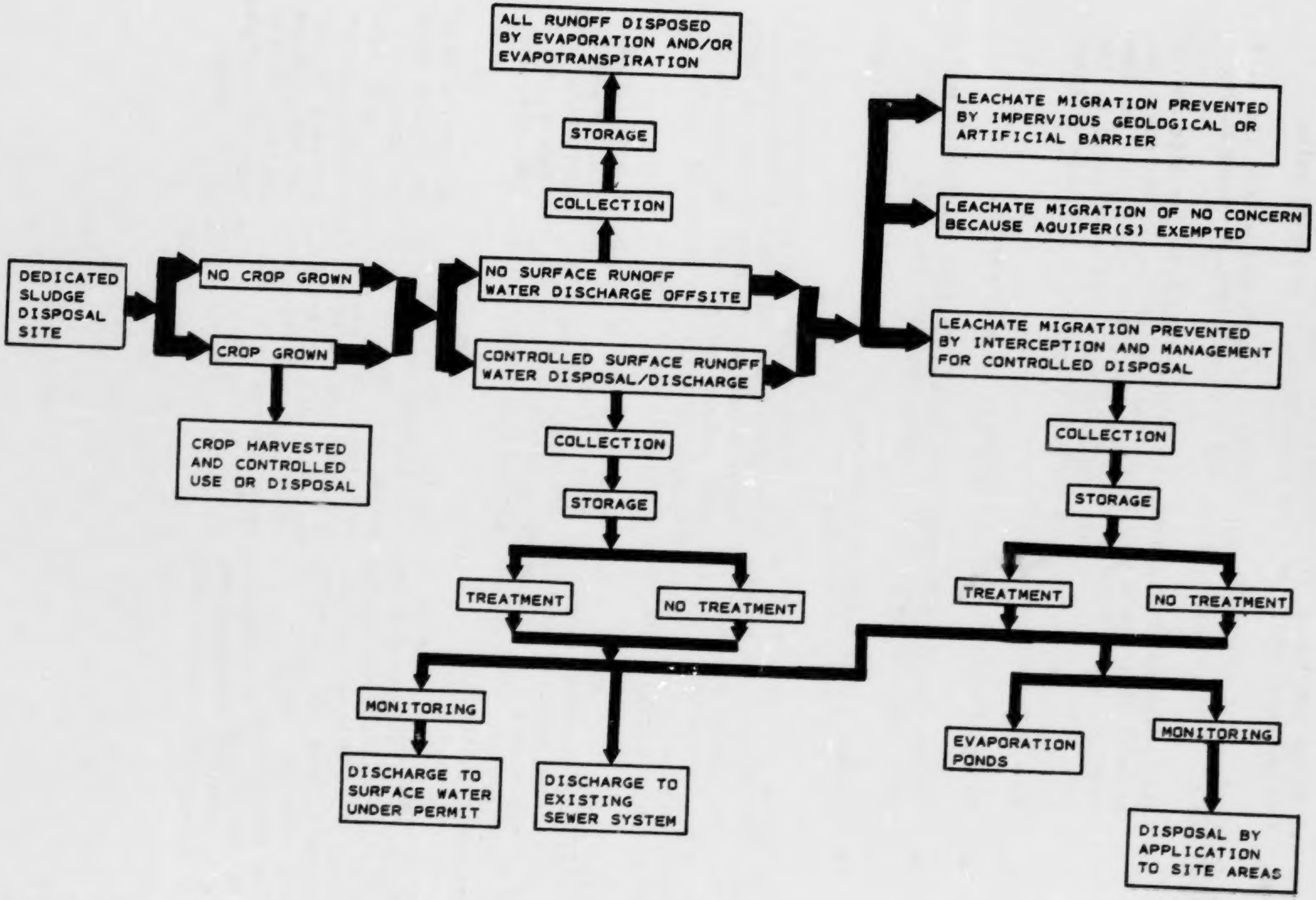
DEDICATED SLUDGE DISPOSAL SITE
NO CROP GROWN
CROP GROWN
CROP HARVESTED AND CONTROLLED USE OR DISPOSAL
NO SURFACE RUNOFF WATER DISCHARGE OFFSITE
CONTROLLED SURFACE RUNOFF WATER DISPOSAL/DISCHARGE
COLLECTION
STORAGE
ALL RUNOFF DISPOSED BY EVAPORATION AND/OR EVAPOTRANSPIRATION
COLLECTION
STORAGE
TREATMENT
NO TREATMENT
MONITORING
DISCHARGE TO SURFACE WATER UNDER PERMIT
DISCHARGE TO EXISTING SEWER SYSTEM
LEACHATE MIGRATION PREVENTED BY IMPERVIOUS GEOLOGICAL OR ARTIFICIAL BARRIER
LEACHATE MIGRATION OF NO CONCERN BECAUSE AQUIFER(S) EXEMPTED
LEACHATE MIGRATION PREVENTED BY INTERCEPTION AND MANAGEMENT FOR CONTROLLED DISPOSAL
COLLECTION
STORAGE
TREATMENT
NO TREATMENT
EVAPORATION PONDS
MONITORING
DISPOSAL BY APPLICATION TO SITE AREAS

Figure 9-1. Alternatives in consideration of dedicated sludge disposal site design.

Which design alternative is best for any specific new project is dependent on site-specific factors, such as:

- Climate, which affects timing of sludge application, and hence sludge storage required, crops (if any) which can be grown, etc.

- Site soil and hydrogeology, which affect the extent of ground water leachate control needed, soil surface preparation, method of sludge application, crops (if any) which can be grown, amount of runoff, etc.

- Site size and topography, which affect sludge application rates, feasibility of constructing large storage lagoons, method of sludge application, runoff control, size of buffer zone, etc.

- Availability of a sewerage system, which can be used for controlled disposal of surface runoff and/or leachate.

9.5 Site Investigations

Chapters 4 and 5 discussed the procedures and data necessary in the site selection and evaluation process. Because a DLD site is normally a long-term operation, sludge application rates are high, and since containment of sludge contaminants is necessary, the designer is often required to conduct more extensive site investigations than are necessary for agriculture and other types of applications.

Ideally, the area selected for the dedicated disposal site would:

- Be near the treatment plant(s) so as to reduce sludge transport costs.

- Have easy transport (e.g., road, pipeline, etc.) access.

- Be underlain with an impervious geological barrier, e.g., bedrock, continuous thick clay layer, etc, or be underlain with an exempted aquifer, i.e., an aquifer which is useless because of existing poor water quality.

- Have a large buffer area interspersed between it and areas of public dwellings, public use areas, etc.

- Be distant from surface waters, e.g., lakes, ponds, rivers, streams, etc.

- Have gentle slopes (e.g., <3 percent) to minimize site grading, and other improvement costs.

- Be in an area of temperate, arid climate with high net evaporation.

- Have convenient access to an existing sewer system for controlled discharge of collected surface runoff and/or leachate.

- Have heterogeneous soil with adequate drainage permeability, high cation exchange capacity (CEC), and pH of above 6.5.

As a minimum, the designer will require the following data:

- Climate history, e.g., precipitation (annual, monthly, maximum year storms, number of days with rainfall above 0.3 cm (0.1 in), evaporation (annual, monthly), and temperatures (number of days below freezing). See Section 4.7 for discussion of sources of climate data.

- Sludge data, present and future, i.e., quantity, physical characteristics, chemical characteristics, transport method, etc.

- Topography of the site and surrounding area, i.e., slopes, surface waters (streams, ponds, etc.), roads, wells, structures, improvements, drainage, flooding potential, existing vegetation, etc.

- Soil properties of the site, physical and chemical.

- Hydrogeological properties, i.e., depth to ground water, depth to aquifers, quality and use of ground water, ground water flow direction, existence of impermeable or low permeability layers (e.g., bedrock, clay).

- Site ownership, land use zoning, restrictions, etc.

All of the above site investigation data are discussed in detail in Chapters 4 and 5. Table 9-2 lists typical siting criteria for a DLD site.

9.6 Environmental Constraints in Dedicated Land Disposal Site Design

9.6.1 General

Various potential contaminants in sludge are discussed in Appendix A. The interaction of these contaminants with soil and their fate in the environment are discussed in Appendix B. The principal potential contaminants of concern are excess nitrogen (in the nitrate form), heavy metals, persistant organics, and pathogens. By definition, it is the intent of the DLD site to contain these contaminants within the site or manage their movement off-site in a controlled, environmentally acceptable manner. Therefore, virtually all state regulatory agencies in 1982 considered proposed DLD projects on a case by case basis. Regulations for agricultural utilization and other "beneficial" uses of sludge are generally not applicable to DLD sites. Restrictions on the use and management of DLD sites are generally more severe than for "beneficial" uses. The proponents must demonstrate that the design and management of the project provides the necessary safeguards.

TABLE 9-2
SITING CRITERIA FOR DEDICATED LAND DISPOSAL

Parameter	Unacceptable Condition	Ideal Conditions
Slope	Deep gullies, slope >12%	<3%*
Soil	Permeability $>1 \times 10^{-5}$ cm/sec†	$\leq 1 \times 10^{-7}$ cm/sec#
	<0.6 m (2 ft) in-situ thickness	>3m (10 ft) in-situ thickness
Surface Water (distance to)	<92 m (300 ft) to any pond or lake used for recreational or livestock purposes, or any surface water body officially classified under state law	>305 m (1,000 ft) from any surface water body
	In special flood hazard areas or recognized wetlands	>61 m (200 ft) from intermittent streams
Ground Water	<3.1 m (10 ft) to ground water table (wells tapping shallow aquifers)**	>15.3 m (50 ft) to ground water table
Wells (potable)	Water supply wells within 305 m (1,000 ft) radius	No wells within 610 m (2,000 ft) radius

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* Ideal slope depends on solid content (TSS) and sludge application method. See Table 5-1 for general slope limitations.

† Pervious soil can be used for DLD if appropriate engineering design preventing DLD leachate from reaching the ground water is feasible.

# When low-permeable soils are too close to the surface, liquid disposal operation can be hindered due to water ponding.

** If an exempted aquifer underlies the site, poor quality leachate may be permitted to enter ground water.

9.6.2 Nitrogen Control at Dedicated Land Disposal Sites

One of the keys to an acceptable DLD site is control of nitrates to prevent contamination of ground water aquifers. The possibilities are:

1. There is no useful ground water aquifer below the site which can be affected; either the aquifer(s) is exempt (of such poor quality that it is not subject to non-degradation regulations) or none exists at potentially useful elevations.
2. The local climate is arid with a high net evaporation, and useful aquifers are deep. For example, at the DLD site used by

Denver, Colorado, it was found that precipitation, which averages 36 cm (14 in) annually, is insufficient to percolate to any significant depth, and potable water is from 100 to 300 m (330 to 980 ft) below the ground surface.

3. An impervious geological barrier, e.g., bedrock or thick clay, lies between the DLD site and the useful aquifer effectively preventing significant volumes of leachate from percolating into the aquifer.

4. A below ground leachate interception system is constructed, e.g., drain tiles, well points, etc., which collect the leachate before it can percolate into the aquifer.

5. It can be shown that the volume of leachate containing nitrates reaching the aquifer is such a small percentage of the ground water aquifer flow volume that potential degradation is negligible.

If none of the above possibilities is feasible, singly or in combination, then a DLD site will probably not be feasible.

9.6.3 Sludge Metals at Dedicated Land Disposal Sites

The safeguards discussed in Section 9.6.2 for protection of ground water for nitrate contamination will serve for metals also. The long-term accumulation of metals on a DLD site will eventually have an adverse effect on most crops.

9.6.4 Sludge Pathogens at Dedicated Land Disposal Sites

Ground water protection measures described in Section 9.6.2 should adequately contain pathogens also. A DLD site is designed to prevent surface runoff so there is no potential contamination from this source either. Vectors (flies, rodents, etc.) control is needed to prevent off-site migration and on-site breeding. Adequate buffer zones will control aerosols and odor complaints. Control of public access to the site is essential.

9.6.5 Persistent Organics Control at Dedicated Land Disposal Sites

As discussed in Appendix A, most sludges contain only low concentrations of persistant organics. Further, persistent organics contained in sludge are generally not very mobile in soil, e.g., they are adsorbed in the upper soil layers. Therefore, unless the sludge is unusually high in toxic persistent organic compound concentrations and the site soil is very permeable (e.g., sand) and leachate controls are not adequate, the containment of persistent organics within the site should be readily achieved.

9.6.6 Aesthetics at Dedicated Land Disposal Sites

The major aesthetic concern at most DLD sites is odor. Odor control at sludge application sites is discussed in Chapter 11.

Basically, odor problems from sludge are always the result of anaerobic (septic) conditions. When applying large quantities of liquid sludge, the soil should be maintained in an aerated condition via surface drainage (no ponding), subsurface drainage, and/or tillage (if necessary). Subsurface injection by sludge application vehicle(s) provides another alternative to reduce odors.

Liquid sludge storage lagoons are a potential source of odor. If the sludge is well stabilized, odor problems are usually infrequent, but may occur (e.g., during a spring thaw after extended cold weather, or during a major disturbance of the sludge lagoon as would occur during bottom sediment cleanout). Typical attempts at controlling odors from sludge lagoons involve (1) locating the sludge lagoon in the DLD site as far from public access areas as possible, (2) providing as large a buffer area around the site as possible, and (3) adding lime to the lagoon. Use of a facultative lagoon (see Chapter 10), if properly designed, will reduce the potential for odors. Obviously, if the POTW sludge treatment process is having problems, e.g., a sour digester, the resulting poorly stablized sludge should, if possible, not be added to the DLD site storage lagoon.

Dust and noise may result from use of heavy equipment (e.g., tractors, subsurface injector vehicles, etc.) at sludge application sites. In an agricultural area dust and noise should be no worse than expected from normal farming operations, and should create no problems. In an urban area, use of buffer zones and vegetative screening (trees, shrubs, etc., around the site) may be necessary to mitigate public impact.

Table 9-3 lists criteria adapted at the Sacramento, California, DLD site.

9.7 Preliminary Design of Dedicated Land Disposal Sites

9.7.1 General

Chapter 10 of this manual covers design of many of the facilities and improvements involved in a DLD site, e.g., clearing, grading, roads, fencing, buildings, lights, storage facilities, surface water drainage, etc. This section covers those aspects which are of special importance to DLD sites.

TABLE 9-3
ODOR, DUST, AND HAZARD DISTANCE CRITERIA ADOPTED FOR THE SACRAMENTO, CALIFORNIA, DLD SITE (4)

Regional Plant Process Unit	Potential for Adverse Effect	Distance Criteria Used
Sludge storage basins	Odor potential is significant. After studies and mitigation measures it appears that these units can meet the criteria in all but a few instances each year.	610 m (2,000 ft)
Dedicated land disposal	Odor measurements on subsurface injection show minimal odors. Surface spreading and subsequent incorporation would have some odor potential. Also, infrequent summer rain could cause odor. There is slight potential for dust, less than typical farming operations.	305 m (1,000 ft) due to dust, slight odor potential, and accidental spillage of sludge on land surface.
Ash disposal (grit and Screening Emergency Disposal)	Slight odor from grit and screenings disposal. Dust will be generated from landfill-type disposal operation.	610 m (2,000 ft)

Note: Two odor units at site boundary or fence line under maximum conditions is the basic odor criteria used. Distances have been developed through the following:

- Odor potential of source.
- Mitigation potential.
- Case histories in other locations.
- Distance availability.

9.7.2 Climate Considerations

Climate is particularly important in the design of dedicated land disposal sites. The designer should obtain the following historical information for the past 20 years:

1. Precipitation, by month and year, average and maximum.
2. Twenty-five year storm intensity; also 50 and 100 year storms.
3. Evaporation rate from water surface, by month and year, average and minimum.
4. Annual number of days of precipitation over 0.3 cm (0.1 in), average and maximum.
5. Annual number of days below freezing, average and maximum.

See Section 4.6 in Chapter 4 for climate information services.

In addition, it is useful to know the local evaporation rate from soils (usually about 70 percent of that from water surfaces) and evapotranspiration rate estimated from the types of local vegetation (if any) being considered for planting on the site. This information may be available from local university agricultural extension services, or federal assistance agencies.

The climate information listed above is used in many aspects of the site design including:

- Designing surface runoff collection, storage, and control structures.
- Determining necessary sludge storage capacity.
- Determining the area requirements for sludge spreading.
- Determining any necessary leachate collection and storage systems.

Figure 9-2 depicts the major pathways for water entering a project which the designer should attempt to quantify in design of a DLD site.

9.7.3 Vegetation Considerations at Dedicated Land Disposal Sites

Table 9-4 presents the major advantages and disadvantages of growing vegetation on a DLD site. DLD sites surveyed during preparation of this manual were about equally divided between bare land operation and use of vegetation.

9.7.4 Surface Runoff Storage Volume Required

DLD sites usually require that storage be provided for surface runoff resulting from precipitation. Figure 9-3 illustrates various alternatives for disposing of surface runoff. These can range from disposal by evaporation only in an arid area such as Arizona, to combined disposal by evaporation, controlled discharge, and return for reapplication to the site, such as is practiced at the Fulton County, Illinois, site which receives sludge from the city of Chicago.

It is beyond the scope of this manual to develop all the hydrological calculations which may enter into making an accurate assessment of the maximum runoff which can be expected from a specific site. An experienced hydrological designer is necessary and should develop curves for a maximum precipitation year which plot precipitation, runoff, evaporation, etc., for the site area. Based upon the curves, an estimate can be made of the runoff storage volume and surface area needed.

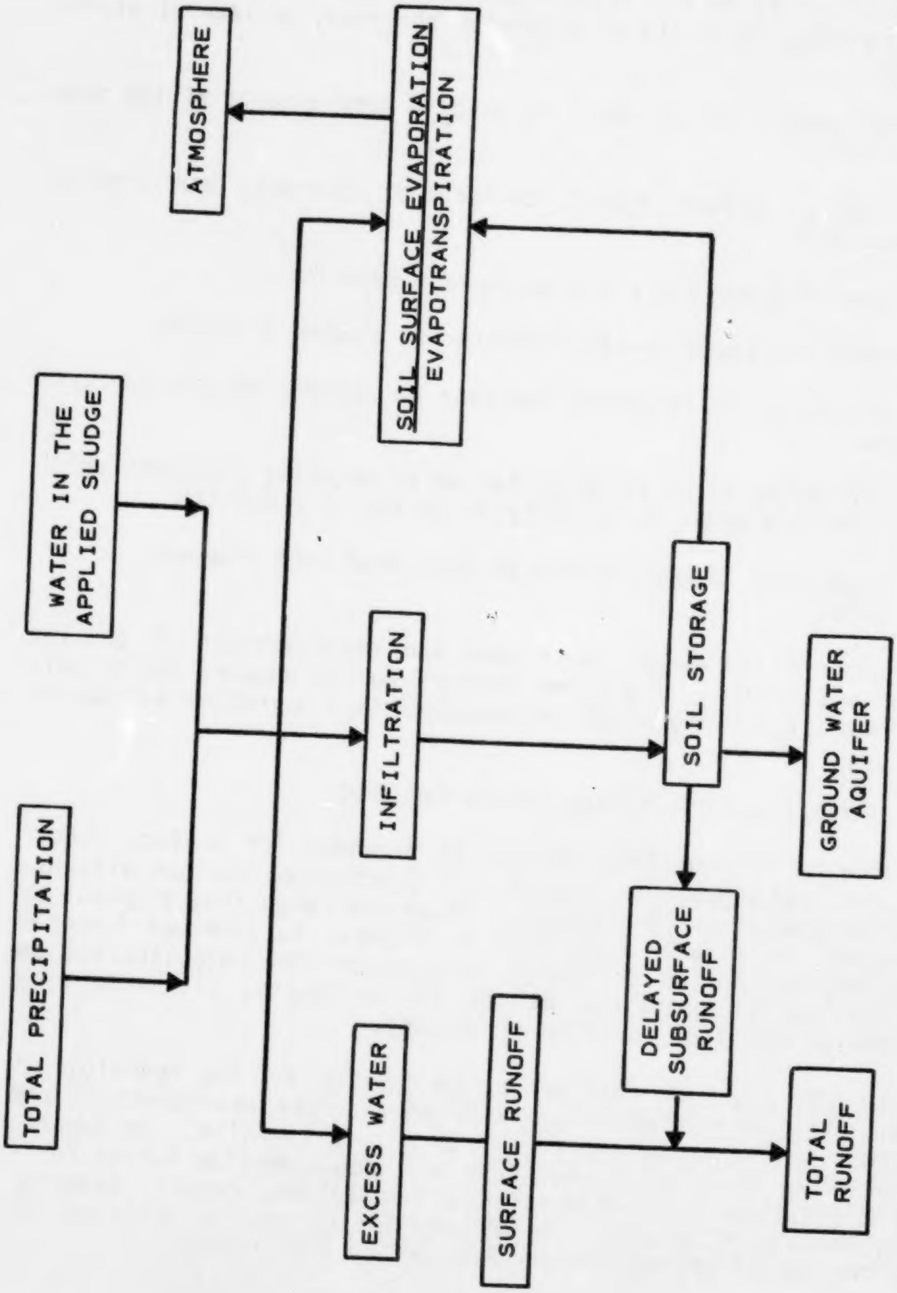


Figure 9-2. Fate of water received by dedicated sludge disposal site.

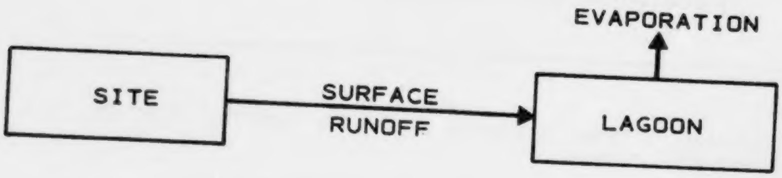
TABLE 9-4
ADVANTAGES AND DISADVANTAGES OF GROWING VEGETATION ON DEDICATED LAND DISPOSAL SITES

A. Advantages

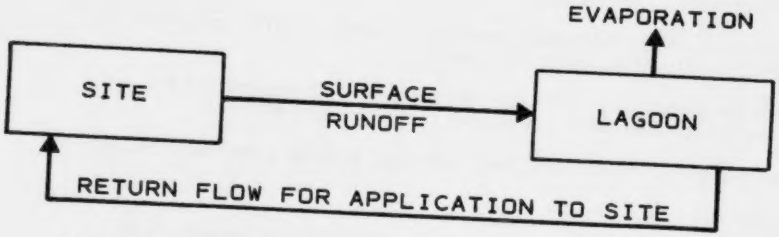
1. If surface soil is "tight" and drains poorly, the plant root structure may improve soil drainage.
2. Plants will enhance water removal through evapotranspiration.
3. Plants will help to reduce surface runoff volume from precipitation.
4. Plants will take up a portion of the nitrogen, metals, and other sludge constituents applied by incorporating them during growth. If the plants are harvested and used or disposed in a controlled manner, the constituents incorporated in the plants are removed from the site.
6. The DLD site will more closely resemble a normal farming operation and be more visually pleasing to the public.
7. Some of the sludge nutrients will be recycled into vegetation and may serve as a positive public relations factor to many citizens.
8. Harvesting of the plants and their sale may provide a monetary return.

B. Disadvantages

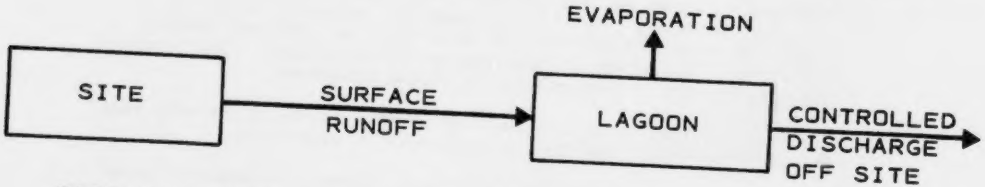
1. Sludge application scheduling is more complex since it usually must operate around the seeding, cultivation, and harvesting operations. Planted areas may be "off limits" for high rate sludge application during many months, often the best months for sludge application from an operations viewpoint.
2. Planting, cultivation, and harvesting of plants can be labor and equipment intensive. Capital equipment and operating costs are increased over those for a DLD site which does not grow and harvest vegetation. Management is more complex since agronomic considerations are added to the primary mission of sludge management.
3. The area required for sludge application site may be larger with vegetation involvement than for a project with no vegetation.
4. Planted areas attract animals which could become a nuisance or serve as vectors.
5. Planted areas may result in more unauthorized public entry, e.g., children climbing fences.
6. Harvested plants may contain metal concentrations too high for human or animal consumption necessitating controlled disposal.
7. After years of heavy sludge application, the soil may become phytotoxic to plants effectively ending any potential for agricultural operations at the site.



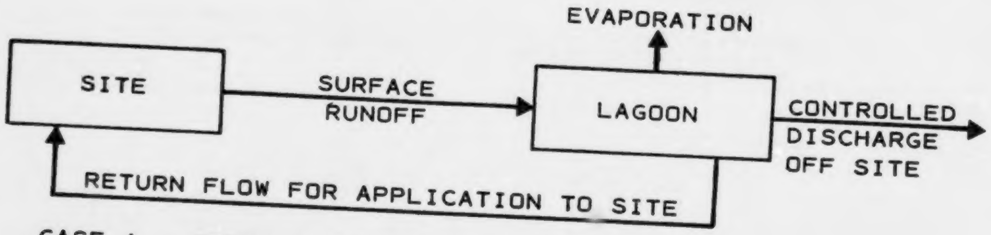
CASE 1 - SURFACE RUNOFF DISPOSAL BY EVAPORATION FROM LAGOON SURFACE ONLY.



CASE 2 - SURFACE RUNOFF DISPOSAL BY EVAPORATION FROM LAGOON TO SURFACE PLUS RETURN OF STORED RUNOFF TO THE SITE FOR APPLICATION.



CASE 3 - SURFACE RUNOFF DISPOSAL BY EVAPORATION FROM LAGOON SURFACE PLUS CONTROLLED DISCHARGE FROM LAGOON TO SURFACE WATER, SEWER, ETC.



CASE 4 - COMBINATION OF CASE 2 AND CASE 3 ABOVE

Figure 9-3. Alternate considerations for disposal of surface run-off stored in lagoons.

The hydrologic designer will typically use the following information in his design:

- Area of the site.
- Historical precipitation records; normally the designer selects the "wettest" period expected over a period of years (possibly 10, 25, 50, or 100 years), depending upon the degree of safety desired. The degree of safety desired or required by local regulatory officials will vary for particular sites, depending on the economics associated with increased safety and the potential for environmental damage that would be caused by an overflow of the storage lagoon.
- Site runoff; a function of soil type, infiltration, amount of previous recent precipitation, soil moisture retention, and vegetation (if any) at the site.
- Evaporation; from the lagoon surface and the soil surface. If vegetation is present, then evapotranspiration is also a factor.
- Controlled discharge or expected seepage, if any, from the storage lagoon.

9.7.5 Sludge Application Rate Calculations

9.7.5.1 General

Unlike agricultural and forest sludge application options, the application rate of sludge to dedicated disposal sites (as defined in this manual) is not limited by plant uptake (nitrogen fertilizer) and cumulative metal totals, but is limited by the following factors:

- The rate of sludge which can be applied during each application while still maintaining aerobic conditions in the soil. The method of sludge application, soil drainage, soil characteristics, sludge moisture content, and climatic conditions all influence this factor.
- The number of days during the year when sludge can be applied as dictated by weather conditions, ability of the sludge application equipment to operate with existing soil conditions, any vegetation planting/harvest, etc., restrictions (if vegetation is grown on the site), and equipment breakdown and maintenance requirements.
- Evaporation rates if that is the design pathway for sludge liquids.

9.7.5.2 Sludge Application Rates

Annual sludge application rates to DLD sites reviewed during preparation of this manual ranged from 12 dry mt/ha (5 T/ac) up to 2,250 dry mt/ha (1,000 T/ac). The higher application rates are practiced at DLD sites which:

- Receive dewatered sludge.
- Mechanically incorporate the sludge into the soil.
- Have relatively low precipitation.
- Are not faced with leachate contamination of ground water problems because of site conditions or project design.

A conservative approach is to match sludge application and net soil evaporation rates. Sludge application is intensive during warm and dry periods, and reduced during wet or cold periods.

Net soil evaporation is calculated by the use of:

$$E_N = E_S - P \qquad (9\text{-}1)$$

$$E_N = (f \times E_L) - P \qquad (9\text{-}2)$$

where:

E_N = net soil evaporation

E_S = gross soil evaporation

E_L = gross lake evaporation

P = precipitation

f = factor expressing the relationship of soil and lake evaporation (dimensionless).

Typically, gross soil evaporation in an area is estimated as a fraction (e.g., f = 0.70) of the lake evaporation. Estimates can be obtained from local agricultural information services. Table 9-5 illustrates the calculation of net soil evaporation on a monthly basis for Colorado Springs, Colorado (9).

TABLE 9-5
NET MONTHLY SOIL EVAPORATION AT COLORADO SPRINGS, COLORADO (9)

Month	Gross Soil Evaporation (cm)*	Precipitation (cm)	Net Soil Evaporation (cm)
January	-	1.80	-
February	-	1.85	-
March	-	3.96	-
April	9.16	4.85	4.31
May	11.45	5.44	6.01
June	13.55	5.49	8.06
July	14.69	7.62	7.07
August	12.43	5.89	6.54
September	9.58	3.94	5.64
October	7.34	2.82	4.52
November	-	2.41	-
December	-	1.70	-
Annual	78.20	47.78	42.15

* Estimated based on 70 percent lake evaporation.
† Gross soil evaporation less precipitation.
# 1 in = 2.54 cm.

Having estimated net soil evaporation (E_N) for each month, the sludge application rates on a monthly basis are calculated by matching the moisture in the applied sludge against E_N, as shown in Equation (9-3):

$$R_M = \frac{E_N \times TS \times C}{100 - TS} \qquad (9\text{-}3)$$

where:

R_M = monthly sludge application rate (dry mt/ha/mo) or (dry T/ac/mo).

E_N = net soil evaporation (cm/mo) or (in/mo)

TS = total solids content of the sludge (%) by weight

C = a conversion factor which equals 100 mt/cm in metric units or 113.3 T/in in English units.

Table 9-6 shows monthly sludge application rates for the Colorado Springs, Colorado, site, based on a sludge with 4.85 percent solids content and the net monthly soil evaporation rates shown in Table 9-5. Sample calculations for April are:

$$\text{Metric} \quad \frac{4.31 \times 4.85 \times 100}{100 - 4.85} = 22 \text{ mt/ha}$$

$$\text{English} \quad \frac{1.70 \times 4.85 \times 113.3}{100 - 4.85} = 9.8 \text{ T/ac}$$

TABLE 9-6
MONTHLY SLUDGE APPLICATION RATES AT COLORADO SPRINGS, COLORADO, DLD SITE (9)

Month	Monthly Application Rate*	
	(dry mt/ha)†	(dry T/ac)†
January	-	-
February	-	-
March	-	-
April	22.0	9.8
May	30.7	13.7
June	41.1	18.3
July	36.1	16.1
August	33.4	14.8
September	28.8	12.8
October	23.1	10.3
November	-	-
December	-	-
Annual	215.0	95.8

* Total solid content in the sludge is assumed to be 4.85 percent.

† Using Equation (9-3) and data from Table 9-5.

Refering to Table 9-6, an annual average total of 215 mt/ha (95.8 T/ac) dry weight of sludge could be applied at this site using net soil evaporation as a basis.

The use of net soil evaporation as a basis for calculating sludge application rates is obviously conservative since it makes no allowance for moisture removal from the sludge through infiltration into the soil. If infiltration is allowed, sludge application rates can be calculated by the following equation:

$$R_M = \frac{(E_N + I) \times TS \times C}{100 - TS} \qquad (9\text{-}4)$$

where:

I = infiltration rate (cm/mo) or (in/mo), and all other terms are the same as in Equation (9-3).

9.7.5.3 Drying Period Between Sludge Applications

Drying (rest) periods between sludge applications allow the soil to return to its natural aerobic condition. Applications should be scheduled to prevent excessive moisture in the soil for long periods, and to minimize odors and the breeding of vectors.

It is difficult to provide exact guidelines for the length of the drying period because so many factors are involved, e.g.:

- Quantity and moisture content of sludge applied.
- Method of sludge application.
- Net soil evaporation rate and precipitation occurring during the days following application.
- Soil texture and infiltration rate.

Generally, if dewatered sludge is applied and/or the sludge is incorporated into the soil during application, drying periods between applications can be short, e.g., 2 to 3 days, providing the weather is favorable. When liquid sludge is applied to the soil surface without soil incorporation, the drying periods between application should be longer (e.g., 5 to 20 days), depending upon the quantity applied, topography, soil properties, and the weather. Figure 9-4 shows suggested periods between sludge applications as a function of the type of sludge (liquid or dewatered), whether the sludge is incorporated into the soil, and application rate. Figure 9-4 is based on experience at a limited number of DLD sites reviewed and is provided for general guidance only.

Aerobic conditions in the soil are more easily maintained by lighter applications of sludge at more frequent intervals. For example, refering to the upper curve in Figure 9-4 for liquid sludge, not incorporated into the soil, application of 11 mt/ha (5 T/ac) at 7-day intervals is generally preferable to the application of 31 mt/ha (14 T/ac) at 20-day intervals. The heavier sludge application is more likely to cause anaerobic soil conditions condusive to odors and vector breeding.

9.7.6 Land Area Requirements

9.7.6.1 General

Land area requirements for a DLD site comprise the total land needed for sludge disposal, sludge storage, buffer areas, surface runoff control, and supporting facilities. In the following subsections each of these needs is discussed. The prudent designer will incorporate appropriate safety factors into the design to allow for necessary future expansion, and additional facilities.

9.7.6.2 Land Area Requirement for Sludge Disposal

As discussed in Section 9.6.2, acceptable sludge application rates to DLD sites are highly variable depending on sludge characteristics, climate, soil characteristics, and other site specific factors. When the annual sludge application rate has been determined, it is a simple calculation to divide this rate into the present and future estimated

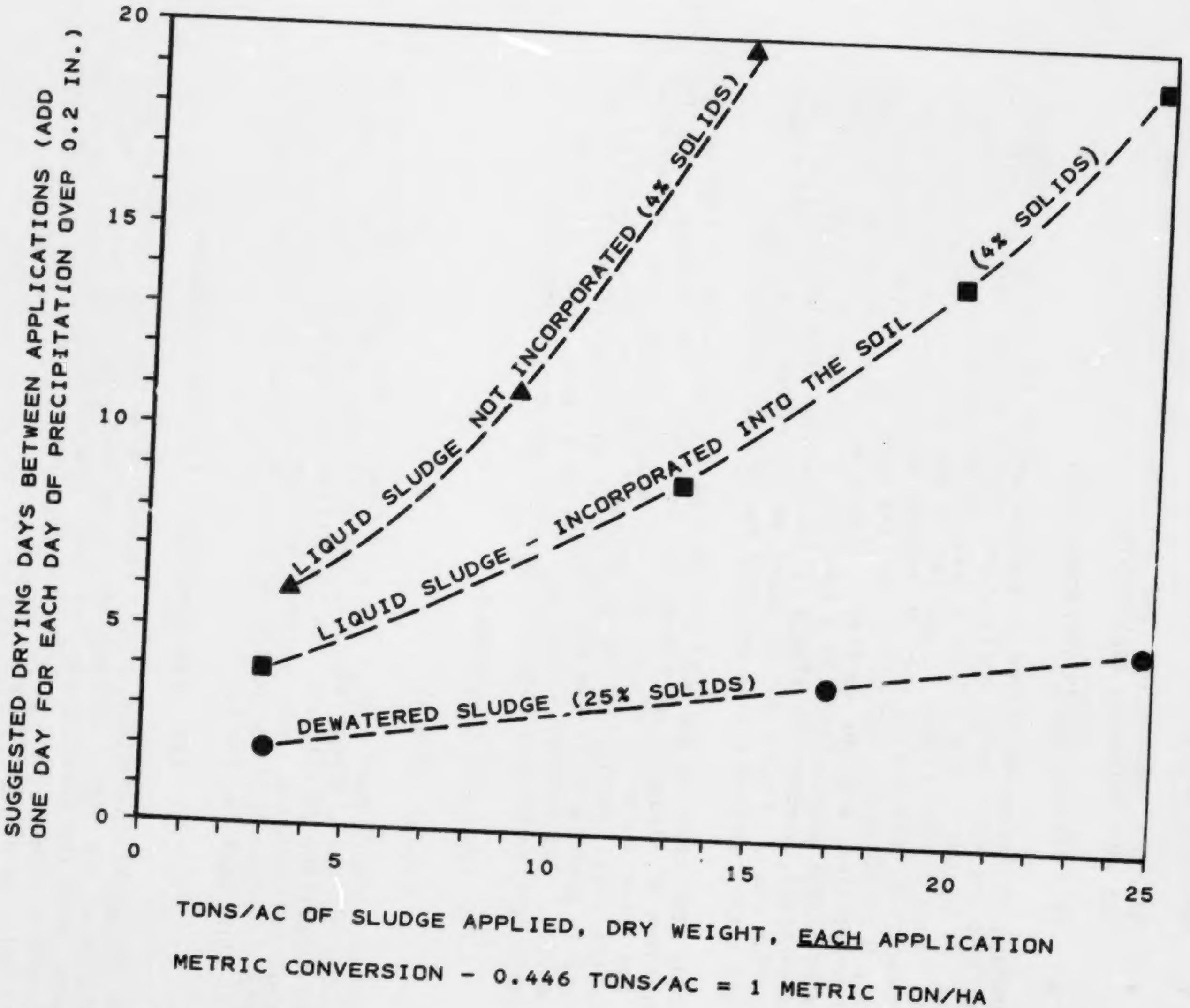


Figure 9-4. Suggested drying days between sludge applications for average soil conditions and periods of net evaporation < 2 in./mo.

quantity of sludge which must be disposed in order to calculate the sludge disposal area required, as shown below:

$$\text{Area required} = \frac{\text{Maximum annual design sludge generation in dry weight}}{\text{Annual application rate in dry weight/unit area}}$$

9.7.6.3 Land Area Requirement for Sludge Storage

Design of sludge storage facilities is discussed in Chapter 10. Sludge storage is virtually always required because adverse weather or other factors prevent the continuous application of sludge to the DLD site. Storage may be located at the POTW, at the DLD site, or both. As a minimum, the sludge storage facilities should have sufficient capacity to retain all sludge generated during nonapplication periods. Liquid sludge is typically stored in lined lagoons or metal tanks. Dewatered sludge is typically stored by mounding in areas protected from runoff.

Calculation of the volume required for liquid sludge storage is detailed in Chapter 10. The procedure takes into account volume of sludge generated, precipitation, evaporation, and other pertinent factors. Often the regulatory agency will stipulate a required sludge storage volume which reflects a time period, e.g., one month storage, two month storage, etc.

In any case, once the necessary storage volume has been established, the land area required for either liquid sludge lagoons or dewatered sludge stockpiles can be determined, based on depth, height, freeboard, berm construction area, etc. As a rough approximation, the land area required equals three times the volume of the sludge to be stored divided by the depth (or height) of the material stored. For example, assume that one million L (35,310 ft^3) of liquid sludge storage is required and the liquid depth of the lagoon is 3 m (9.8 ft). Approximate area required equals 1,000 m^2 (10,800 ft^2).

9.7.6.4 Land Area Requirement for Surface Runoff Capture and Storage

Storage lagoon design is discussed in Chapter 10.

Once the required storage volume has been determined (Section 9.7.4), the necessary land area can be easily calculated based on lagoon depth, freeboard, and berm construction. As noted in Section 9.7.6.3, a rough approximation of land area required can be derived by multiplying by three the volume of the runoff to be stored, and dividing by the depth of the lagoon.

The land area required for surface runoff collection, e.g., drainage ditches, etc., is normally only a small percentage of the total DLD site area (e.g., 2 to 5 percent).

9.7.6.5 Land Area Required for Buffer Zone

The desired width of an acceptable buffer zone will vary, depending upon surrounding land use, and the potential for odor, dust, noise, etc., resulting from site design and operation.

A minimum buffer of 150 m (500 ft) is suggested around any DLD site. A minimum buffer of 600 m (2,000 ft) is suggested around DLD sites when one or more of the following conditions will exist:

- Liquid sludge is stored at the site in open lagoons.
- During application liquid sludge is spread on the soil surface and not quickly incorporated by disking.
- During application liquid sludge is sprayed by use of a wide coverage spray device(s).
- Residential dwellings or other heavy public use areas are adjacent to the DLD site.
- Sludge application rates are heavy and it is anticipated that anaerobic soil conditions will periodically result.

While difficult to quantify, the desirable width of a buffer zone is also a function of the size of the operation, e.g., volume of sludge disposed, application area, etc. The larger the operation the more buffer area is desirable simply because the magnitude of potential nuisance to surrounding property is greater.

9.7.6.6 Land Area Required for Supporting Facilities

Support facilities may include roads, buildings, etc. Compared to other land area requirements previously discussed, the area for these facilities is usually very small, e.g., less than 3 percent of the DLD site total.

9.7.7 Ground Water Leachate Collection and Control

As discussed in Section 9.5, the ideal location for a DLD site is one where ground water contamination from leachate is of no concern because of favorable site conditions. However, if the DLD site is located where it could contaminate potable ground water aquifers, the designer must consider means to intercept the percolating leachate.

Subsurface drainage systems may be needed when natural drainage is restricted by relatively impermeable layers in the soil profile near the soil surface, or by high ground water. As a result of the restrictive layer, shallow ground water tables can extend close to the soil surface. Such a high ground water table may create serious problems in sludge application because of ponding, anaerobic soil conditions, and muddy surfaces.

Buried plastic pipe or clay tile, 10 to 20 cm (4 to 8 in) diameter, are normally used for underdrains. Concrete pipe is less suitable because of the sulphates in leachate from sludge amended soils. Underdrains are normally buried 1.8 to 2.4 m (6 to 8 ft) deep, but can be as deep as 3 m (10 ft) or as shallow as 1 m (3 ft). Spacing of drains typically range from 15 m (50 ft) in clayey soils up to 120 m (400 ft) in sandy soils. Procedures for determining the proper depth and spacing of drain liner are found in Section 5.7 of "The Process Design Manual for Land Treatment of Municipal Wastewater," EPA, October 1981 (17), and in References (18) and (19).

If a subsurface drainage collection system is installed beneath the DLD site, the leachate collected from the system must be treated, stored, and/or disposed of. Alternatives for disposal were shown in Figure 9-1.

9.8 Methods for Application of Sludge to Dedicated Land Disposal Sites

9.8.1 General

The designer has a number of alternatives in selecting the method of applying the sludge to the soil. These are:

- Subsurface application of liquid sludge.
- Surface application of liquid sludge.
- Application of dewatered sludge.

A detailed explanation of sludge application methods is found in Chapter 10 of this manual.

9.8.2 Application of Liquid Sludge

Liquid sludge can be applied either by surface spreading or subsurface injection methods. The latter is often more desirable since it minimizes potential odor and runoff problems.

Surface spreading of liquid sludge, or flooding without subsequent incorporation, is less expensive than subsurface injection in terms of equipment and labor. However, the dedicated land disposal sites reviewed during preparation of this manual had experienced problems when using surface spreading methods. Difficulties that may be encountered with the method include odors, uneven distribution of sludge, clogging of soil surface, and difficult vehicle access into the area.

9.8.3 Application of Dewatered Sludge

The application of dewatered sludge (20 percent solids or more) is similar to that of solid or semisolid fertilizer, lime, or animal manure. Sludge can be spread with bulldozers, front end loaders, graders, or box spreaders, and then incorporated by plowing or disking. The spiked tooth harrows used for normal farming operations may be too light to bury sludge adequately and heavy-duty mine disks or disk harrows may be required.

9.9 Monitoring Requirements

9.9.1. Criteria Pertaining to Water Resource Protection

Regulations promulgated under Sections 1008(a)(3) and 4004(a) of the Resource Conservation Recovery Act, and Section 405(d) of the Clean Water Act, require the following standards for ground and surface waters for all solid waste disposal facilities and practices (12):

Ground Water Standards: A facility or practice must not contaminate an underground drinking water source beyond the waste site boundary or beyond an alternative boundary specified by the state which has an EPA-approved solid waste management plan.

Surface Water Standards: A facility or practice must not:

- Violate the requirements of the National Pollutant Discharge Elimination System (NPDES).
- Cause a discharge of dredged material or fill material to waters of the United States.
- Cause non-point source pollution of waters of the United States or border bodies of water.

9.9.2 Monitoring Needs

A DLD system should be designed in such a manner that it will not contaminate surface and ground water sources. Monitoring programs should basically be designed to insure that the DLD system functions as intended. Chapter 11 of this manual discusses monitoring requirements for various types of sludge to land treatment alternatives. In general, monitoring requirements for dedicated land disposal sites are more extensive than for other types of sludge land application options, and may include:

- Monitoring of applied sludge quantities and characteristics.
- Monitoring of changes in site soil characteristics, physical and chemical.
- Monitoring of ground water quality beneath the site and adjacent to the site in the direction of ground water flow; monitoring of both saturated and unsaturated zones, and at various depths may be required.
- Monitoring of surface water runoff from the site.
- Monitoring of surface waters potentially affected by the site.
- Monitoring of odor, dust, and/or aerosol emissions from the site.

9.9.3 Closure and Post-Closure Care Plans

Closure and post-closure plans of a retired DLD site may be the last phase of waste management at the site. Acceptable closure practices are generally similar to those of landfills (12) and should be:

- Technologically sound with respect to protection of local water resources.
- Compatible with the projected future use of the site (i.e., golf course, park, parking lot, etc.).

The designer should identify any post-closure requirements of the responsible regulatory agency in the area where the DLD site is located.

9.10 Design Example

The design example is for a community of 400,000 located in Central California. A specific site has been tentatively selected, cognizant regulatory agencies have been contacted, and a public participation program initiated.

The existing POTW utilizes a conventional activated sludge process which generates a mixture of primary and waste activated sludge. The sludge is anaerobically digested. Approximately 25 percent of the wastewater treated is from industry, primarily seasonal food processing wastewaters.

9.10.1 Sludge Generation and Characteristics

Table 9-7 projects sludge production from 1980 through 1999. Table 9-8 shows characteristics of the sludge.

9.10.2 Climate

Average climatological data for the area is presented in Table 9-9. Evaporation is recorded at locations 17 miles to the east, and 12 miles to the west. High daytime temperatures and low humidity in the summer account for the pronounced evaporation rates. Average annual rainfall is 42 cm (17 in), but varies from a minimum of 12 cm (5 in) to a maximum of 92 cm (36 in) with maximum 1-hour and 24-hour rainfalls recorded at 4.19 cm (1.65 in) and 8.94 cm (3.52 in), respectively.

9.10.3 State and Local Regulations of Concern

The appropriate regulatory agencies have advised that the site would probably be subject to the following regulations:

- Off-site wastewater discharge: none would be preferred. If necessary to have a discharge, the NPDES permit would stipulate essentially drinking water quality.

TABLE 9-7
PROJECTION OF DIGESTED SLUDGE PRODUCTION FOR DESIGN EXAMPLE

	Digested Sludge Production			
Year	(Wet) m^3/yr	Dry mt/yr	M gal/yr	Dry ton/yr
1980	756 x 10^3	17,000	197.9	18,700
1985	786 x 10^3	18,000	205.7	19,800
1992	936 x 10^3	22,300	245.0	24,500
1999	1,007 x 10^3	25,100	263.6	27,600

TABLE 9-8
TYPICAL CHARACTERISTICS OF DIGESTED AND LAGOONED SLUDGE FOR DESIGN EXAMPLE

Constituent	Concentration*
Total solids, %	2.68
Volatile solids, %	1.54
Total nitrogen, %	7.5
Phosphorus, %	2.5
Arsenic, mg/kg	6-13
Cadmium, mg/kg	27-51
Chromium, mg/kg	52-213
Copper, mg/kg	280-560
Lead, mg/kg	96-210
Mercury, mg/kg	11-16
Nickel, mg/kg	72-193
Selenium, mg/kg	3-9
Silver, mg/kg	7-14
Zinc, mg/kg	1,080-1,723

* All concentrations are exressed on a dry weight basis.

- Ground water leachate percolation: None would be preferred. If necessary to have leachate, monitoring is required to ensure that ground water at the project boundary meets drinking water standards.

- Flood control facilities need to protect against site flooding by the maximum 100-year storm.

- Sludge must be incorporated into soil during or immediately after sludge application to prevent/minimize odors.

- A minimum of 3 months of sludge storage capacity must be provided. If sludge storage is in open ponds, a minimum distance of 610 m (2,000 ft) must be provided from the sludge storage ponds to the nearest site boundary.

9.10.4 Characteristics of the Site

The area selected for the DLD site has flat topography with a maximum elevation difference of 6 m (20 ft) within the 240 ha (600 ac) investigated. The surrounding area is predominantly farm land.

Results of soil borings are shown in Table 9-10. While this is obviously a simplified version of an extensive soils report, the summary notes that the upper 3 to 6 m (10-20 ft) of the site consist of soils of very low permeability, including a central layer with permeability of 1 x 10^{-9} cm/sec, or less, which appears continuous at depths of 3 to 6 m (9 to 20 ft). The free ground water is confined below this layer, which provides an essentially impermeable barrier to downward migration of surface leachate. Soil is dense and slowly permeable.

9.10.5 Determination of Sludge Application Rates

For this design example sludge application rates will be estimated based upon positive net soil evaporation rates, as was discussed in Section 9.6.2. It may be preferable to conduct tests on experimental plots for several years to determine more optimum sludge application rates.

Table 9-11 shows the monthly net soil evaporation rate for the area. Table 9-12 shows the monthly sludge application rate based upon Equation (9-3):

$$R_M = \frac{EN \times TS \times C}{100 - TS}$$

presented in Section 9.6.2. An example calculation for the month of May follows:

$$\text{(Metric)} \quad R_M = \frac{13.17 \times 2.68 \times 100}{(100) - (2.68)} = 36.3 \text{ mt/ha/mo}$$

$$\text{(English)} \quad R_M = \frac{5.19 \times 2.68 \times 113}{(100) - (2.68)} = 16.1 \text{ T/ac/mo}$$

TABLE 9-9
AVERAGE CLIMATOLOGICAL DATA FOR THE SLUDGE APPLICATION AREA FOR DESIGN EXAMPLE

Month	Air Temperature (°C)	Air Temperature (°F)	Precipitation (cm)*	Evaporation (cm)† Low	Evaporation (cm)† High
January	7.3	45.2	8.08	2.24	4.52
February	9.5	49.2	7.59	3.73	5.77
March	11.9	53.4	5.99	8.18	12.27
April	14.7	58.4	3.56	12.98	19.66
May	17.8	64.0	1.50	20.96	28.35
June	21.4	70.5	0.25	24.28	32.39
July	24.1	75.4	0	27.99	33.43
August	23.4	74.1	0.05	25.07	29.49
September	22.0	71.6	0.48	19.08	24.03
October	17.5	63.5	1.96	11.63	16.23
November	10.5	50.9	4.58	4.45	6.60
December	8.0	46.4	8.23	2.29	3.86
Annual	-	-	42.24	162.88	216.46

* Long-term average data.
† Metric conversion 1 cm = 0.39 in.

TABLE 9-10
SOIL CHARACTERISTICS OF DEDICATED LAND DISPOSAL SITE FOR DESIGN EXAMPLE*

Depth From Surface	Dominant Unified Soil Classification	Vertical Permeability cm/sec
0 - 3 m (0 - 10 ft)	Silty clays (CL) Organic clays (OH) Clayey silts (ML)	1×10^{-10} to 5×10^{-8}
3 - 6 m (9 - 20 ft	Cemented soils in two layers. Upper layer is silty clay (CL) and lower layer is fine sandy silt (ML) and silty fine sand (SM)	1×10^{-9} to 1×10^{-10}
6 - 13 M (19 - 40 ft	Clean fine to medium sands	3×10^{-4} to 1×10^{-6}

* Ground water surfaces range from 4 to 15 m (13 to 46 ft) below surface.

TABLE 9-11
NET SOIL EVAPORATION AT DEDICATED LAND DISPOSAL SITE FOR DESIGN EXAMPLE

Month	Lake Evaporation (cm*)	Soil Evaporation (cm†)	Precipitation (cm#)	Net Soil Evaporation	
				cm	in
January	2.24	1.57	8.08	(6.51)	(2.56)
February	3.73	2.61	7.59	(4.98)	(1.96)
March	8.18	5.73	5.99	(0.26)	(0.10)
April	12.98	9.09	3.56	5.53	2.18
May	20.96	14.67	1.50	13.17	5.19
June	24.28	17.00	0.25	16.75	6.60
July	27.99	19.59	0.60	19.59	7.72
August	25.07	17.55	0.05	17.00	6.70
September	19.08	13.36	0.48	12.88	5.07
October	11.63	8.14	1.96	6.18	2.43
November	4.45	3.11	4.58	(1.47)	(0.58)
December	2.29	1.60	8.23	(6.63)	(2.61)
Annual	162.88	114.02	42.24	71.78	28.28

* Uses lowest evaporation from Table 9-9.
† Uses 70 percent of lake evaporation.
# Uses average from Table 9-9.
** Metric conversion = 1 cm = 0.39 in.

Based upon this theoretical approach, the annual cumulative sludge application rate to the site shown in Table 9-12 is 250 mt/ha (112 T/ac), dry weight. No sludge would be applied during the "wet" season from November through March.

Based on an annual sludge application rate (dry weight) of 250 mt/ha (112 T/ac), and annual sludge generation in 1980 of 17,000 mt/yr (18,700 T/yr) per Table 9-7, a simple division determines that the sludge application area required in 1980 is 68 ha (167 ac).

Referring to future estimates of sludge generation shown in Table 9-7, the sludge application area required increases as follows:

Year	Area Required	
	Ha	Ac
1980	68	167
1985	72	177
1992	89	219
1999	100	247

TABLE 9-12
MONTHLY SLUDGE APPLICATION RATES FOR DESIGN EXAMPLE BASED ON NET SOIL EVAPORATION

	Net Soil Evaporation*		Monthly Application Rate, Dry Weight†	
Month	cm	in	mt/ha/mo	T/ac/mo
January	(6.51)	(2.56)	-	-
February	(4.98)	(1.96)	-	-
March	(0.26)	(0.10)	-	-
April	5.53	2.18	15.2	6.8
May	13.17	5.19	36.3	16.1
June	16.75	6.60	46.1	20.5
July	19.59	7.72	53.9	24.0
August	17.00	6.70	46.8	20.8
September	12.88	5.07	35.4	15.8
October	6.18	2.43	17.0	7.6
November	(1.47)	(0.58)	-	-
December	(6.63)	(2.61)	-	-
Annual	71.78	28.28	250.7	111.6

* From Table 9-11.

† Uses Equation (9-3) in Section 9.6.2:

$$R_M = \frac{EN \times TS \times C}{100 - TS}$$

where:

R_M = monthly sludge application rate.

EN = net soil evaporation (from Table 9-11).

TS = total solids content of the sludge, equals 2.68 percent (Table 9-8).

C = A conversion factor which equals 100 mt/cm in metric or 113 T/in in English units.

9.10.6 Sludge Storage For Design Example

Sludge storage volume is required for the period when sludge is not applied to the site, i.e., the 5-month "wet" season from November through March. This is 2 months longer than the 3-month storage "required" by the state. Table 9-13 shows the calculation for required monthly sludge storage. As can be seen in the last column, a sludge storage volume in 1980 of 283,000 m^3 (75 M gal) is required.

TABLE 9-13
CALCULATION OF SLUDGE VOLUME STORAGE NEEDS
FOR 1980 SLUDGE GENERATION FOR DESIGN EXAMPLE

Month	1980 Wet Sludge Volume* $m^3 \times 10^3$	Sludge Application Rate† (mt/ha/mo)	Wet Sludge Volume Applied# $m^3 \times 10^3$	Change in Storage $m^3 \times 10^3$	Cumulative Storage $m^3 \times 10^3$
October	63	17	51	12	12
November	56	-	-	56	68
December	51	-	-	51	119
January	50	-	-	50	169
February	51	-	-	51	220
March	52	-	-	52	272
April	57	15.2	46	11	283
May	69	36.3	110	-41	242
June	71	46.1	139	-68	174
July	80	53.9	163	-83	91
August	80	46.8	142	-62	29
September	76	35.4	107	-31	-2
Annual	756	250.7	758		

* Wet sludge volume generated from example city records. Summer increase due to seasonal food processing industrial wastewater.

† Sludge application rate from Table 9-12.

# Wet sludge volume applied equals sludge application rate in dry metric ton/ha x application area of 68 ha x 44.5 m^3 of wet sludge per metric ton of dry sludge solids (see Table 9-7).

** Conversion factors: 1 m^3 = 265 gal; one mt/ha/mo = 0.446 T/ac/mo.

The sludge storage volume required increases proportionately to sludge volume generated in subsequent years as shown in Table 9-7, as follows:

Year	Sludge Storage Volume Required $m^3 \times 10^3$	 M gal
1980	283	75
1985	294	78
1992	350	93
1999	377	100

This is a preliminary calculation. It is necessary to check the effect of precipitation and evaporation on the proposed sludge ponds before design finalization, as shown in the following subsection.

9.10.7 Sludge Storage Design

Design of sludge storage facilities is discussed in Chapter 10. For this example, the designer decided to provide open storage lagoons with diked sides and heavy clay lining to prevent seepage. Four lagoons are provided with a capacity of 94×10^3 m^3 (25 million gal) each. Figure 9-5 shows the general arrangement of the four lagoons.

To obtain the final sludge storage volume required for design purposes, it is necessary to check the effect of evaporation from the liquid sludge surface and precipitation falling on the liquid sludge surface and the exposed inside slopes of the containment berms. Seepage is assumed to be negligible. Table 9-14 shows these data. By coincidence, the necessary final maximum storage volume for 1980 calculated in Table 9-14 is the same as was preliminarily determined in Table 9-13. Had the precipitation been higher and evaporation lower, as it is in much of the country, the final storage volume determined would have been greater than the preliminary calculation in Table 9-13, and the designer would have had to adjust the sludge pond depth to accommodate the excess precipitation.

Many considerations other than volume required enter into design of the sludge storage lagoons, including:

- Piping and appurtenance involved in adding and removing sludge, as well as interconnections between sludge ponds.
- Construction of sludge ponds, including lining of wetted portion, erosion control on dike slopes, dike construction, etc.
- Number and size of storage ponds.

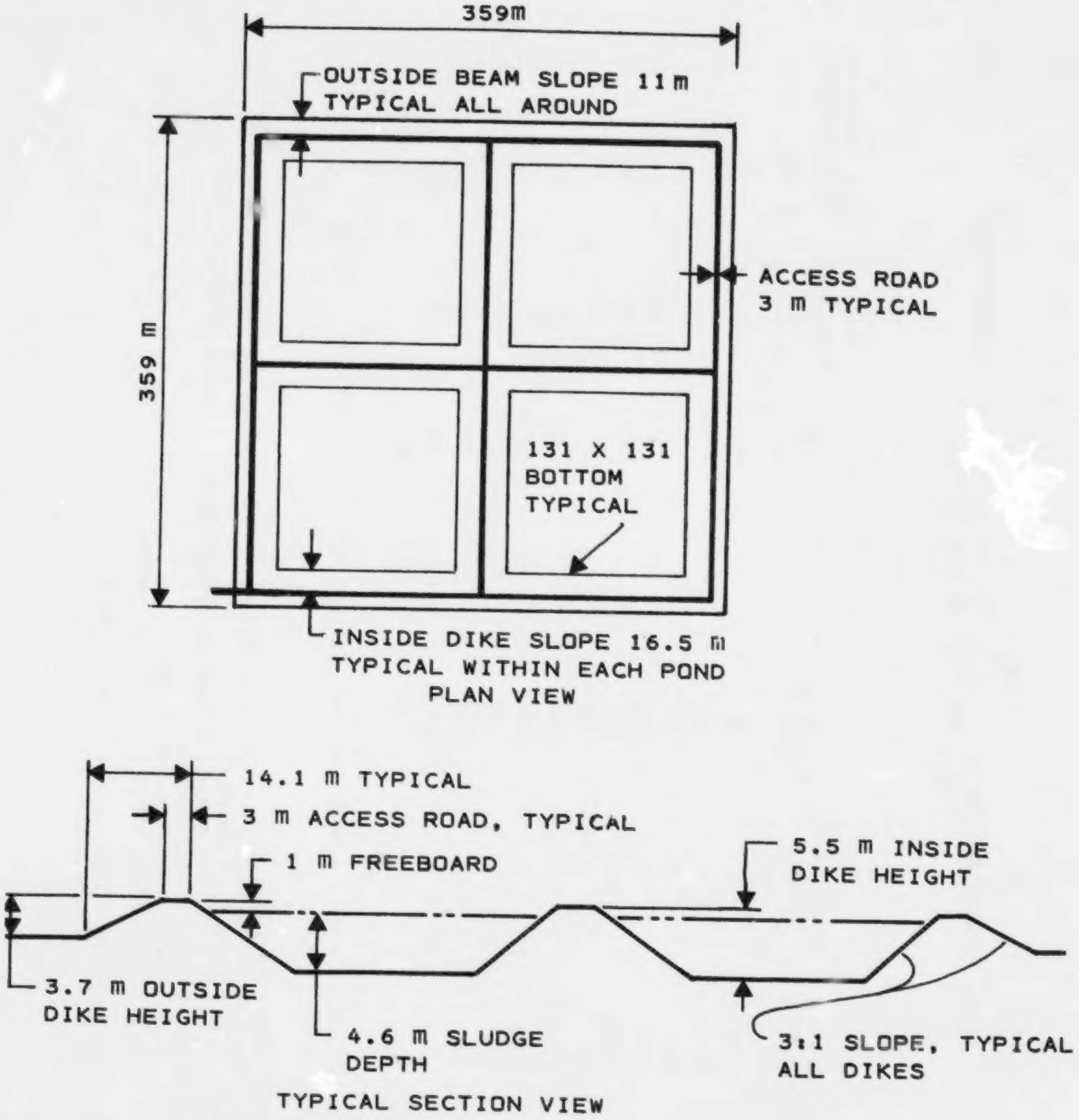


Figure 9-5. Sludge storage ponds, conceptual design.

TABLE 9-14
FINAL DETERMINATION OF STORAGE VOLUME IN SLUDGE STORAGE BASINS FOR 1980, FOR DESIGN EXAMPLE

Month	(1) Precipitation (cm)	(2) Precipitation Volume ($m^3 \times 10^3$)	(3) Evaporation (cm)	(4) Evaporation Volume ($m^3 \times 10^3$)	(5) Net Gain of Loss ($m^3 \times 10^3$)	(6) Change in Sludge Volume Storage ($m \times 10^3$)	(7) Final Cumulative Volume Required	
							$m \times 10^3$	M gal
October	1.96	2	11.63	12	-10	12	2	1
November	4.58	5	4.45	4	1	56	59	16
December	8.23	9	2.29	2	7	51	117	31
January	8.08	9	2.24	2	7	50	174	46
February	7.59	8	3.73	3	5	51	230	61
March	5.99	7	8.18	8	-1	52	281	74
April	3.56	4	12.98	13	-9	11	283	75
May	1.50	2	20.96	21	-19	-41	223	59
June	0.25	0	24.28	24	-24	-68	131	35
July	0	0	27.99	28	-28	-83	20	5
August	0.05	0	25.07	25	-25	-62	0	0
September	0.48	1	19.08	19	-18	-31	-	-
Annual								

Notes:

Column 1 - From Table 9-10.
Column 2 - Column 1 x 0.01 cm/m x surface area on which precipitation falls (see Figure 9-5, 109.4 x 10^3 m^2)
Column 3 - From Table 9-10, low evaporation.
Column 4 - Column 3 x 0.01 cm/m x liquid surface area (see Figure 9-5, = 100.5 x 10^3 m^2).
Column 5 - Equals Column 2 minus Column 4.
Column 6 - From Table 9-14, change in storage column.
Column 7 - Equals Column 6 plus Column 5 plus previous months.

Conversion factors: 1 cm = 0.3937 in; 1 $m^3 \times 10^3$ = 0.265 M gal.

It is assumed that the designer will utilize accepted engineering practices in preparation of the final storage pond(s) design.

9.10.8 Surface Runoff Control for Design Example

The basic objectives of surface water control design is to minimize the volume of runoff water which contacts the disposed sludge, and to manage the runoff water which has contacted the sludge/soil mixture.

Chapter 10 of this manual, and standard hydrological design texts discuss various methods of surface water drainage control. This design example will focus on storage and management of the surface runoff which has contacted the sludge/soil mixture and must be managed in an environmentally exceptable manner.

9.10.8.1 Surface Runoff Storage Volume Required

The stored runoff water will be discharged to a collection sewer which returns to the POTW. However, the sewer has limited capacity, and it is necessary to store the runoff and bleed it into the sewer over time. Design criteria for this case are:

- Maximum 100-year storm = 8.94 cm (3.52 in) in 24 hours and 14.48 cm (5.70 in) in 72 hours.
- Maximum runoff for the site = 37 percent of precipitation.
- Sludge application area in 1980 = 68 ha (167 ac) and in 1999 = 100 ha (247 ac).
- Sewer capacity for discharge of stored runoff = 7,600 m^3/day (2 M gal/day).

For preliminary design purposes, the surface runoff storage volume is calculated as follows for 1999:

$$SR = [(P_{72}) \times (SA) \times (\%\ RD)] - (D_{72})$$

where:

SR = Runoff storage required
P_{72} = Maximum 72-hour precipitation
SA = Sludge-amended (application) area
% RD = % runoff from site soil, expressed as a fraction
D_{72} = Quantity which can be bled off to sewer in 72 hours

$$(14.48 \text{ cm} \times \frac{1 \text{ m}}{100 \text{ cm}} \times 100 \text{ ha} \times 10{,}000 \text{ m}^2/\text{ha} \times 0.37)$$

$$- (\frac{7{,}600 \text{ m}^3}{24 \text{ hr}} \times 72 \text{ hr}) = 30{,}776 \text{ m}^3 \text{ (8.1 M gal)}$$

Assuming one rectangular, open basin, with bermed side slopes of 3:1 and effective liquid depth of 3 m (10 ft), the total basin area required is approximately 1.6 ha (4 ac).

9.10.9 Other On-Site Improvements Area Required

For preliminary design purposes, it is assumed that the land area requirements for other improvements are as follows:

- On-site drainage collection: 3 percent of sludge application area = 0.03 x 100 ha = 3 ha (7.4 ac).
- On-site roads, structures, fencing: 5 percent of sludge application area = 0.05 x 100 ha = 5 ha (12.4 ac).

9.10.10 Total Site Area Required

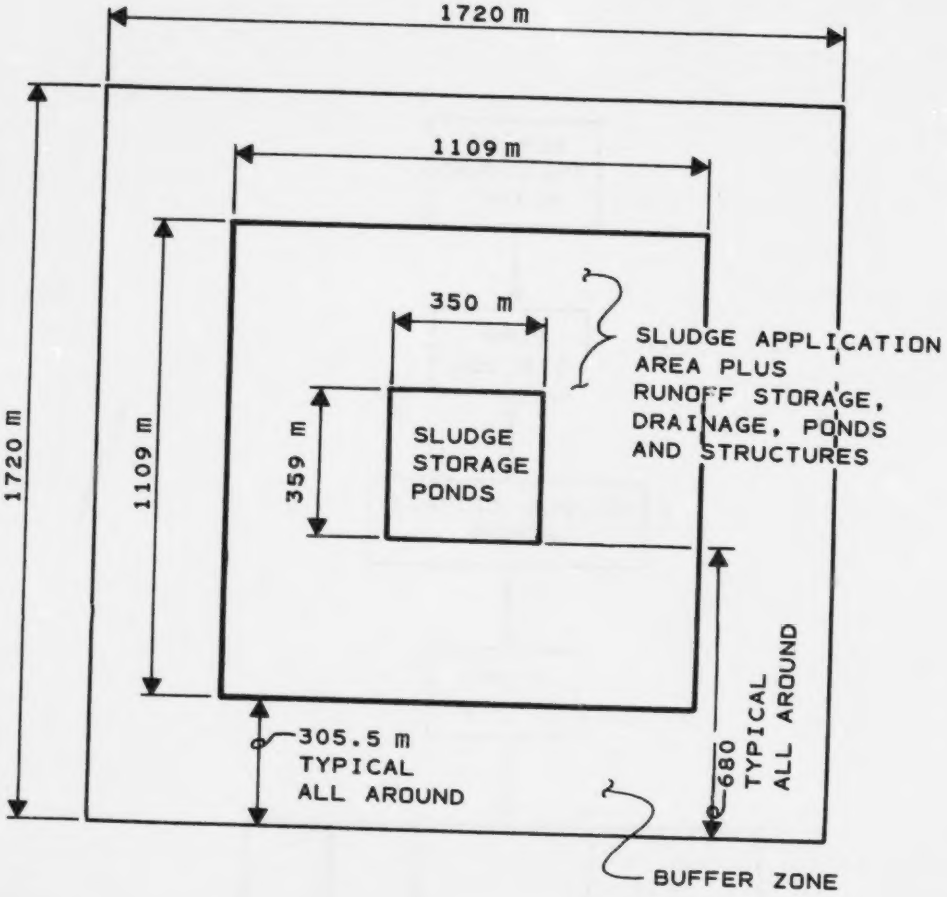
Site area required excluding buffer zone is totaled as followed for the ultimate design to the year 1999.

- Sludge application area = 100 ha (247 ac).
- Sludge storage basins = 13 ha (32 ac).
- Surface runoff storage basin = 1.6 ha (4 ac).
- On-site drainage collection = 3 ha (7.4 ac).
- On-site roads, buildings, etc. = 5 ha (12.9 ac).

The total site area excluding buffer zone = 122.6 ha (303 ac). However, the responsible regulatory agency has indicated that a minimum distance of 610 m (2,000 ft) must be provided from the sludge storage ponds to the site boundary, and a minimum distance of 305 m (1,000 ft) be provided from the sludge application area to the site boundary. Assuming a square site, the minimum total site dimensions, including the buffer zone, are 1,720 m x 1,720 m (5,642 ft x 5,642 ft) as shown in Figure 9-6. Total area required is 296 ha (731 ac).

9.10.11 Sludge Application Method

Sludge will be pumped via pipeline from the POTW to the sludge storage ponds located near the center of the dedicated land disposal site. Sludge will be applied from May through October. Dredged sludge is pumped from the sludge storage pond to the application area through a buried pipeline to field hydrants, and subsequently to flexible hoses which are connected to subsurface injectors (Figures 9-7 and 9-8). While dragging the hose, the subsurface injector will traverse the length of the disposal site, turn 180° at each end, and return in a path


1720 m
1720 m
1109 m
1109 m
350 m
359 m
SLUDGE STORAGE PONDS
SLUDGE APPLICATION AREA PLUS RUNOFF STORAGE, DRAINAGE, PONDS AND STRUCTURES
305.5 m TYPICAL ALL AROUND
680 TYPICAL ALL AROUND
BUFFER ZONE

SUMMARY OF AREAS REQUIRED FOR SQUARE SITE:

1. SLUDGE STORAGE BASINS (SEE FIGURE 9-5) -------13 HA

2. SLUDGE APPLICATION AREA --------100 HA
   SURFACE RUNOFF BASIN-----------1.6 HA
   ON-SITE DRAINAGE----------------3 HA
   ON-SITE ROADS, BUILDINGS--------5 HA

   TOTAL----------(109.6 HA (271 AC)

3. BUFFER ZONE---------------------173.4 HA
   TOTAL AREA REQUIRED-------------296 HA

Figure 9-6. Design example site area required, theoretical for a square site.

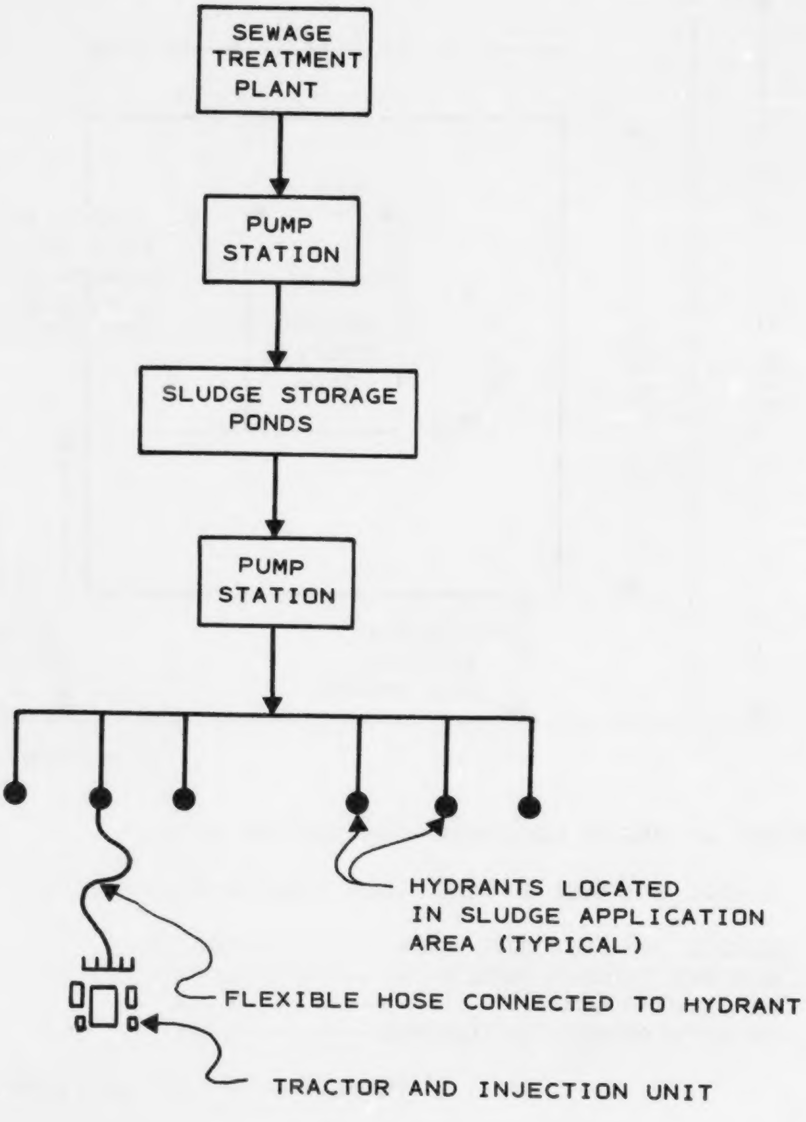
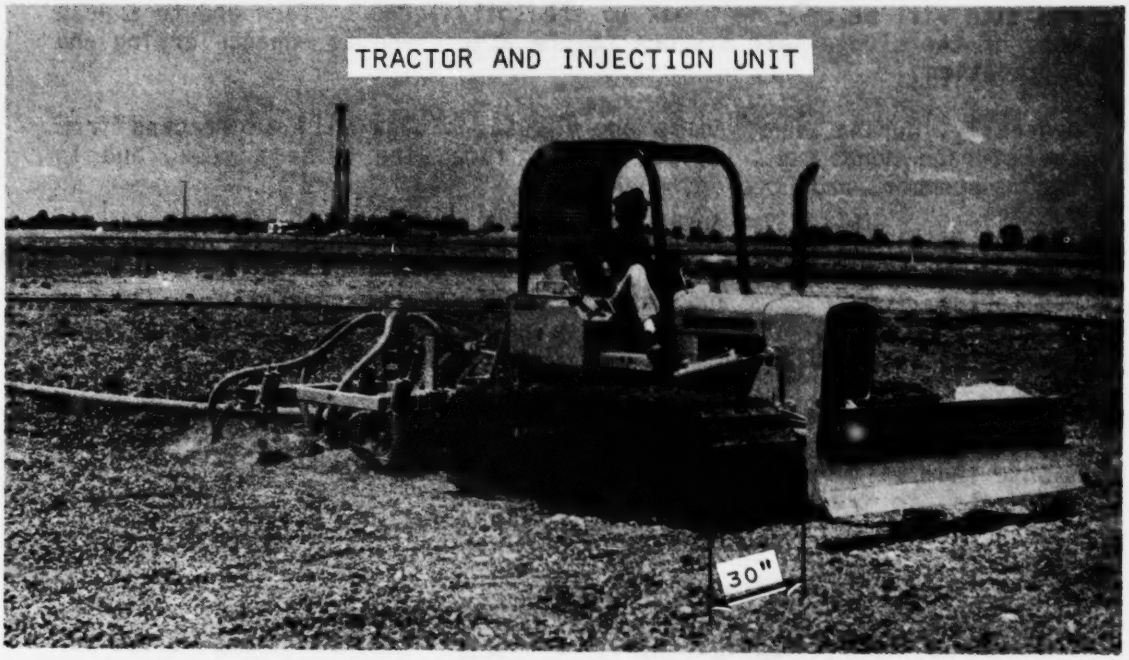

SEWAGE TREATMENT PLANT
PUMP STATION
SLUDGE STORAGE PONDS
PUMP STATION
HYDRANTS LOCATED IN SLUDGE APPLICATION AREA (TYPICAL)
FLEXIBLE HOSE CONNECTED TO HYDRANT
TRACTOR AND INJECTION UNIT

Figure 9-7. Schematic diagram of sludge pumping and application method.



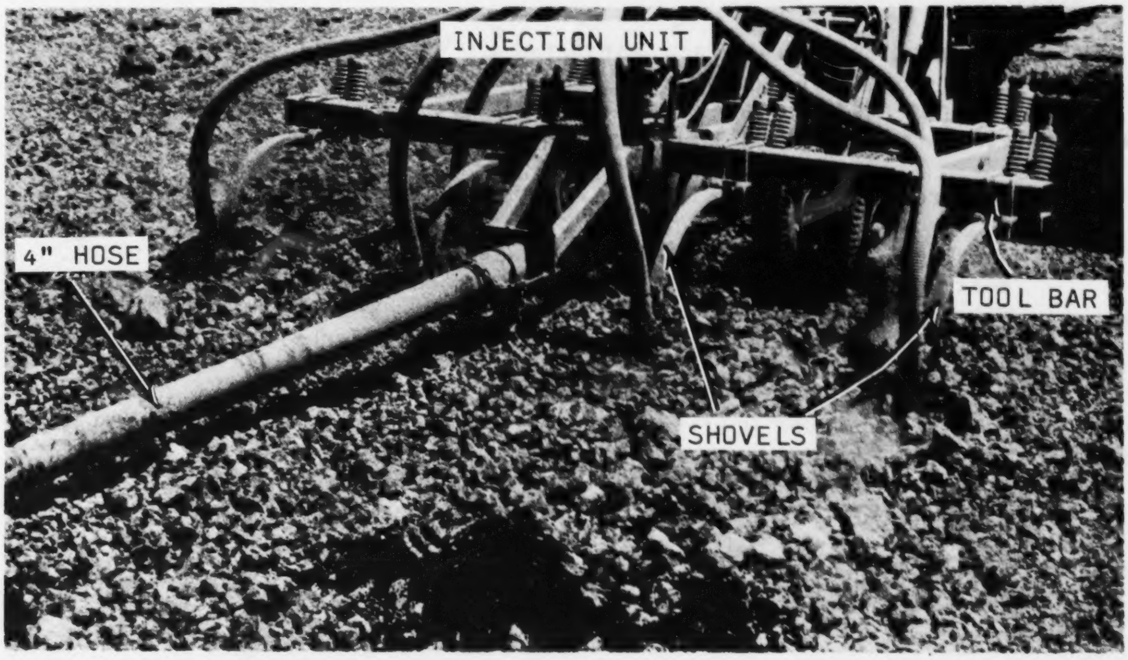


Figure 9-8. Tractor and injection unit.

adjacent to the preceding pass. In normal operation, freshly applied solids remain unexposed to the atmosphere. However, regular disking of the site will be used to break up the soil/sludge surface and to expose more of the sludge-soil mixture to the atmosphere to enhance drying and degradation.

Generally, during June, July, and August, sludge will be removed from the storage ponds, and applied to the same site twice a week, and in May, September, and October, once a week.

9.10.12 Monitoring Requirements for Sample Design

Monitoring requirements and methods are discussed generally in Chapter 11 of this manual. For this sample design, locations, frequency, and parameters analyzed or recorded are shown in Table 9-15.

In addition to the monitoring shown in Table 9-15, micrometerological and odor monitoring will be routinely conducted. An odor complaint response team will be formed, to check on all odor complaints from nearby residents, to track them to the source, if possible, and to provide a written record.

9.10.13 Cost Estimates

Preliminary estimates (1982 costs) for capital and operational costs for the system presented in the sample design are presented in Tables 9-16 and 9-17. Table 9-16 estimates capital costs, including land, but not including transport of sludge to the site, as $12,676,000. Sludge transport to the site is not included because it is a site unique factor.

Annual operational costs are estimated in Table 9-17 at $619,000/yr. Utilizing reasonable equipment life and amortization factors, the unit costs represented are aproximately $109/ dry metric ton ($99/ton), or $26/wet m^3 ($0.10/wet gal) of sludge disposed.

9.11 References

1. Sacramento Area Consultants. Sewage Sludge Management Program. Vol. 1: SSMP Final Report, Work Plans and Source Survey. Sacramento Regional County Sanitation District. Sacramento, California, September 1979. (Available from National Technical Information Service, Springfield, Virginia, PB80 166739.)

2. U.S. EPA. Water Quality Criteria, 1972. EPA R3-73-033, National Academy of Science, Washington, D.C., March 1973. 606 pp. (Available from National Technical Information Service, Springfield, Virginia, PB-236 199)

3. Alexander, M. Introduction to Soil Microbiology. 2d Ed. Wiley, New York, 1977. pp. 225-271.

TABLE 9-15
MONITORING PROGRAM FOR SLUDGE, SOIL, AND WATERS, DESIGN EXAMPLE

Parameter	Sludge		Soils	Ground Water		Creek Water		Surface Runoff
	Daily Storage Pond, Discharge Pumps	Twice Annually#	Annually	Every Other Month	Annually†	Every Other Month	Annually**	Automatic Sampler##
General and Mineral								
Total flow	*	X						
Total solids	*	X	X					
Volatile Solids	X	X						
Specific conductance		X	*	X	X	X	X	X
pH		X	X	X	X	X	X	X
Total alkalinity		X	X	X	X	X	X	X
Chloride		X	X	X	X	X	X	X
Soluble sulfage		X	X					
Calcium		X	X					
Magnesium	X	X						
Potassium		X	X					
Sodium		X	X					
Total phosphate		X	X	X	X	X	X	X
Total nitrogen		X	X	X	X	X	X	X
Nitrate		X	X	X	X	X	X	X
Ammonia nitrogen	X	X	X	X	X	X	X	
COD		X	X	X	*	X	X	X
Dissolved oxygen						X	X	
Temperature						X	X	
Turbidity						X	X	
Hardness				X	X	X	X	X
Heavy Metals								
Arsenic		X	X					
Cadmium		X	*		*		X	
Chromium		X	*		*		X	
Copper		X	X		X		X	
Lead		X	X		*		X	
Mercury		X	X		*		X	
Nickel		X	X		X		X	
Silver		X	X		*		X	
Zinc		X	X		*		X	
Chlorinated Hydrocarbons								
Pesticides		X	X		*		X	
PCB's		X	X		*		X	
Total Organic Halogens		X	X					
Fecal Coliform					*		X	

* Monitoring of this parameter is required by regulatory agency.

X This parameter is monitored.

# From each sludge storage pond.

† Analyze in March.

** Analyze in June.

## Analyze daily when sample is collected.

TABLE 9-16
ESTIMATED CAPITOL COSTS (1982) FOR DEDICATED LAND DISPOSAL SITE USED AS SAMPLE DESIGN

Item No.	Description	Capital Cost 1982 $
1	Sludge pump station at sewage treatment plant and pipeline from sewage treatment plant to the sludge storage ponds located at the dedicated land disposal site.	Not included in the cost total, See Chapter 10
2	Land purchase, 296 ha (731 ac) at $4,446/ha ($1,800/ac).	1,316,000
3	Land grading 296 ha (731 ac) at $2,706/ha ($1,100/ac).	801,000
4	Construction of sludge storage ponds, clay lined with riprap erosion protection, 377,000 m^3 (100 M gal) at $10.56 M^3 ($0.04/gal).	3,981,000
5	Construction of surface runoff storage pond 30,776 M^3 (8.1 M gal) at $11.88/$M^3$ ($0.045/gal).	366,000
6	On-site drainage control structures	250,000
7	On-site roads, gravel, 15,000 m (49,200 ft) at $38.40/m ($11.70/ft).	576,000
8	Fencing, chain link, 1.83 m (6 ft), 4,436 m (14,550 ft) at $49.20/M ($15/ft).	218,000
9	Sludge pump station at sludge storage ponds, 200 hp.	350,000
10	On-site piping, valving, hydrants, etc.	890,000
11	Four subsurface sludge injectors, tractors, and flexible hoses at $160,000 each.	640,000
12	One tillage tractor.	125,000
13	Miscellaneous onsite improvements, including office, workman facilities, lighting equipment warehouse, etc., 558 m^2 (6,000 ft^2) at $7.00/$m^2$ ($65/$ft^2$).	391,000
14	Total estimated capitol cost, including land, but not including transport of sludge to the disposal site.	9,904,000
15	Miscellaneous and contingencies	990,000
16	Engineering costs	990,000
17	Interest during construction	792,000
18	Total estimated capitol cost	12,676,000

TABLE 9-17
ESTIMATED OPERATIONAL COSTS (1982) FOR DEDICATED LAND DISPOSAL SITE USED AS SAMPLE DESIGN

Item No.	Description	Operational Cost 1982 $
1	Labor 6.5 man-years annually at $27,000/man-year, including fringe benefits	176,000
2	Repairs and supplies for mobile equipment	175,000
3	Repairs and supplies for stationary equipment and structures	120,000
4	Energy costs, electricity and fuel	43,000
5	Sampling, monitoring, and anaysis costs	24,000
6	Estimated direct operational costs	538,000
7	Management cost at 15%	81,000
8	Total annual operational cost, 1982	619,000

4. Sacramento Area Consultants. Sewage Sludge Management Program. Volume 7A: Draft Environmental Impact Report. Sacramento Regional County Sanitation District, Sacramento, California, September 1979. (Available from National Technical Information Service, Springfield, Virginia, PB80 166820)

5. U.S. EPA. Process Design Manual for Sludge Treatment and Disposal. EPA-625-1-79-011, Center for Environmental Research Information, Cincinnati, Ohio, September 1979. 1135 pp. (Available from National Technical Information Service, Springfield, Virginia, PB80 200546)

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CHAPTER 10

FACILITIES DESIGN AND COST GUIDANCE

10.1 General

This chapter is intended to aid in design and preliminary cost estimating for:

- Sludge transport equipment.
- Sludge storage facilties.
- Sludge application methods.
- Application site preparation.
- Supporting facilities.

Reference is frequently made in this chapter to two documents that contain additional specific cost and guidance information, and should be obtained and used in conjunction with this chapter. These are:

- Process Design Manual for Sludge Treatment and Disposal U.S. EPA, MERL, ORD, September 1979, EPA-625/1-79-011.

- Transport of Sewage Sludge, U.S. EPA, MER, ORD, December 1977, EPA-600/2/77-216.

The selection and design of any individual component of the system should take into consideration the impact of these decisions upon the overall system efficiency, reliability, and cost. For example, the most economical sludge transportation method may not result in the lowest overall system cost because of resulting higher costs at the treatment plant and/or land application site. The overall system should always be kept in mind when designing its individual components.

10.2 Transportation of Sludge

10.2.1 Transport Modes

Potential modes of sludge transportation include truck, pipeline, railroad, barge, or various combinations of these four modes (Figure 10-1).

The method of sludge transportation chosen and its costs are dependent on a number of factors, including:

- Characteristics and quantity of sludge to be transported.

- The distance from the POTW plant to the application site(s).

- The availability and proximity of the transportation modes to both origin and destination, e.g., proximity of railroad spurs, barge waterways, roads, etc.

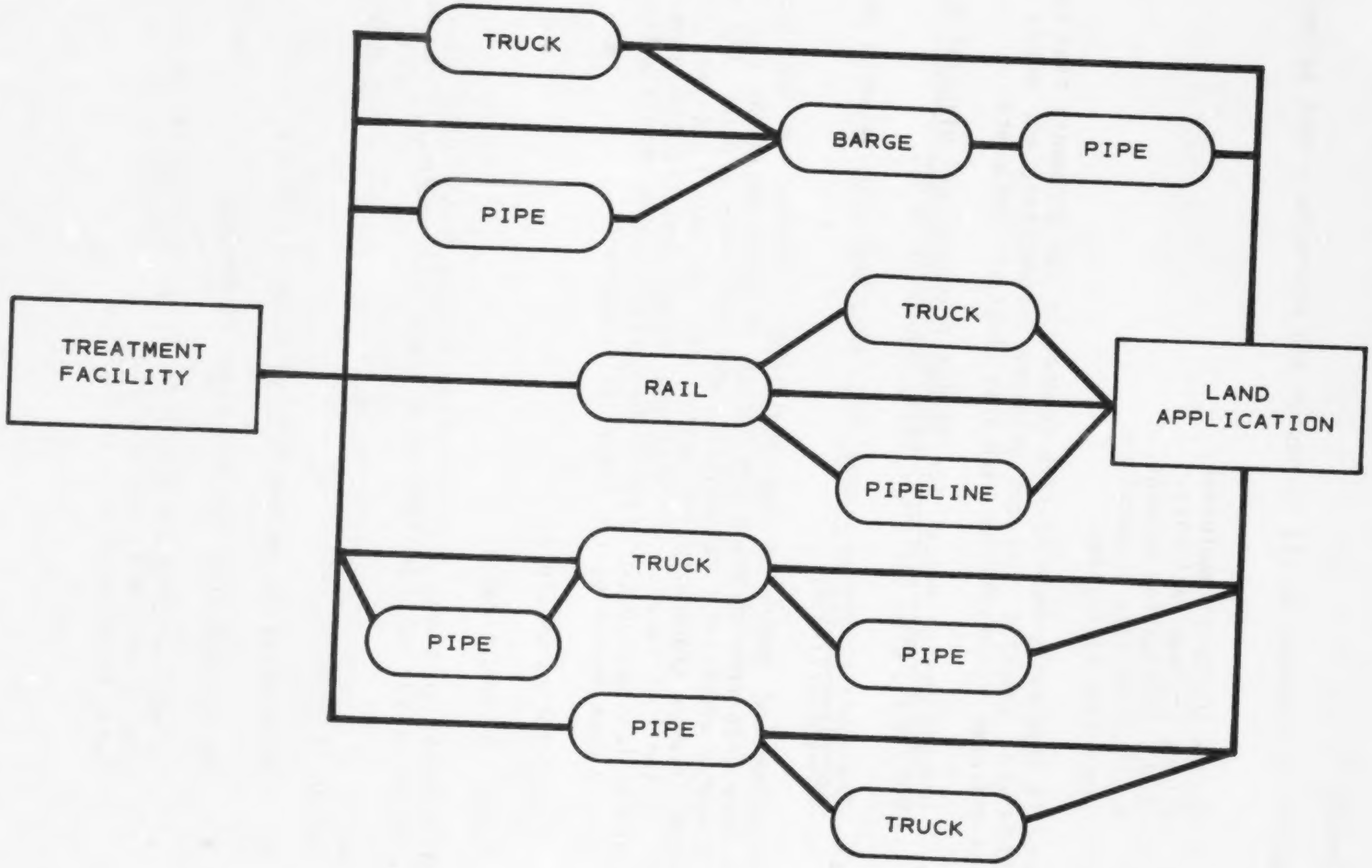


Figure 10-1. Examples of sludge transportation modes and combinations to land application sites.

- The degree of flexibility required in the transportation method chosen.

- The estimated useful life of the sludge land application site, and site characteristics (topography, vegetative cover, soil type, area available).

- Environmental and public acceptance factors.

To minimize the danger of spills, liquid sludges should be transported in closed tank systems. Stabilized, dewatered sludges can be transported in open vessels, such as dump trucks and railroad gondolas if equipped with water tight seals and anti-splash guards (11).

10.2.2 Vehicle Transport

10.2.2.1 Vehicle Types Available

Trucks are widely used for transporting both liquid and dewatered sludges and are generally the most flexible means of transportation. Terminal points and haul routes can be readily changed with minimal cost. Trucks can be used for hauling sludge either to the final application site(s) or to an intermediate transfer point such as railroad yards or a barge loading area. Access to sludge within a site is usually adequate for truck loading.

Many truck configurations are available ranging from standard tank and dump bodies to specialized equipment for hauling and spreading sludges. Depending on the type of sludge to be hauled, the following types of vehicles can be used.

a. Liquid Sludge (Usually Less Than 10 Percent Solids, Dry Weight)

- Farm tractor and tank wagon, such as used for livestock manure. Normally used only for short hauls, and by small rural communities.

- Tank truck, available in sizes from 2,000 to 24,000 l (500 to 6,000 gal)

  - Tank truck adapted for field application of sludge in addition to road hauling.

  - Tank truck only used for road hauling to the land application site(s) and sludge subsequently transferred to field sludge application vehicle or irrigation system. Such tank trucks are often termed "nurse trucks."

b. Dewatered or Composted Sludge (e.g., Usually 20 to 60 Percent Solids, Dry Weight)

- Dump truck, available in sizes from 6 to 23 m^3 (8 to 30 yd^3).
- Hopper (bottom dump) truck, available in sizes from 12 to 19 m^3 (15 to 25 yd^3).
- Either of the above types of truck can be used only for hauling the sludge to the land application site(s), or can be adapted to both haul the sludge and spread the sludge.

Figure 10-2 shows photographs of typical types of the trucks listed above.

10.2.2.2 Vehicle Size and Number Required

To properly assess the size and number of vehicles needed for transporting sludge from the treatment plant to the application site(s), the following factors should be considered:

- Quantity of sludge, present and future.
- Type of sludge, liquid, dewatered, or composted.
- Distance from treatment plant to application site(s) and travel time.
- Type and condition of roads to be traversed, including maximum axle load limits and bridge loading limits.
- Provisions for vehicle maintenance.
- Scheduling of sludge application. In many areas, there is a large seasonal variation (due to weather, cropping patterns, etc.) in the quantity of sludge which can be applied. The transport system capacity should be designed to handle the maximum anticipated sludge application period, taking into consideration any interim sludge storage capacity available.
- Percent of time when the sludge transport vehicles will be in productive use. A 1977 study (1) of truck sludge hauling at 24 small to medium size communities showed that liquid sludge haul trucks were in productive use an average of 48 percent of the time (range 7 to 90 percent) based upon an 8-hr day and 5-day week. Average use for dewatered sludge haul truck was reported even less at 29 percent.

Tables 10-1 and 10-2 provide a guideline for estimating the number of trucks needed for transporting liquid and dewatered sludge, respectively. While the tables provide a means for making preliminary comparisons, they are only a starting point in the decision making process for

Figure 10-2A. 6,500-gallon liquid sludge tank truck (courtesy of Brenner Tank Co.).

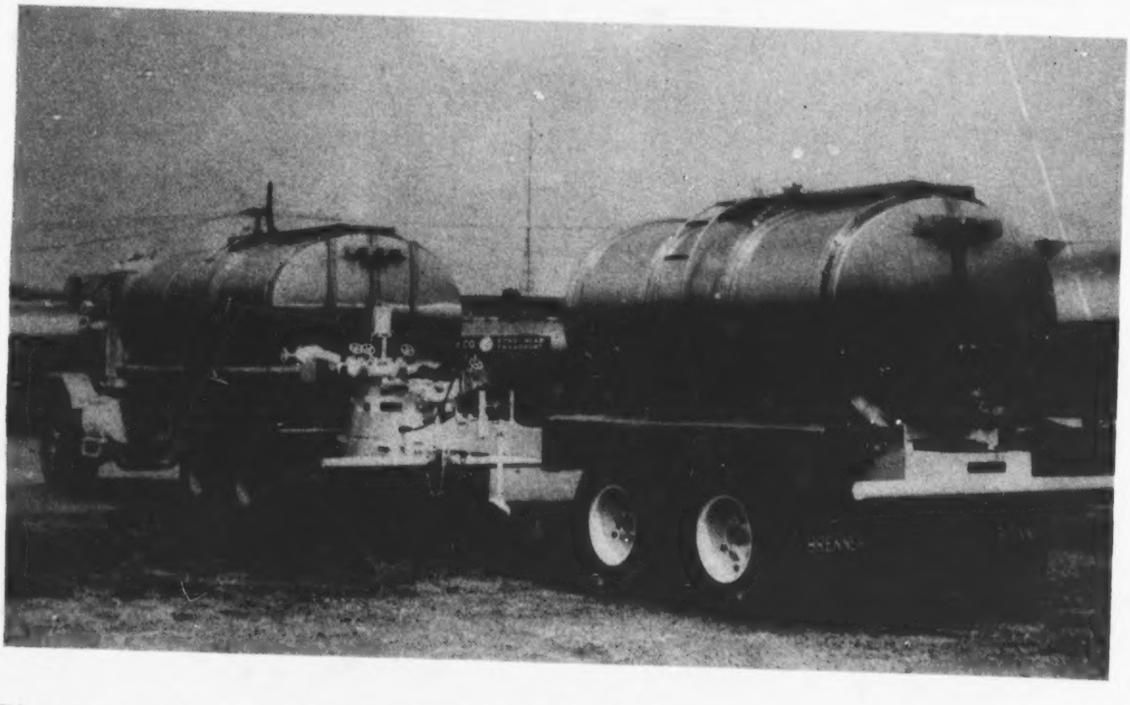


Figure 10-2B. 3,300 gallon liquid sludge tank truck with 2,000-gallon pup trailer (courtesy of Brenner Tank Co.).

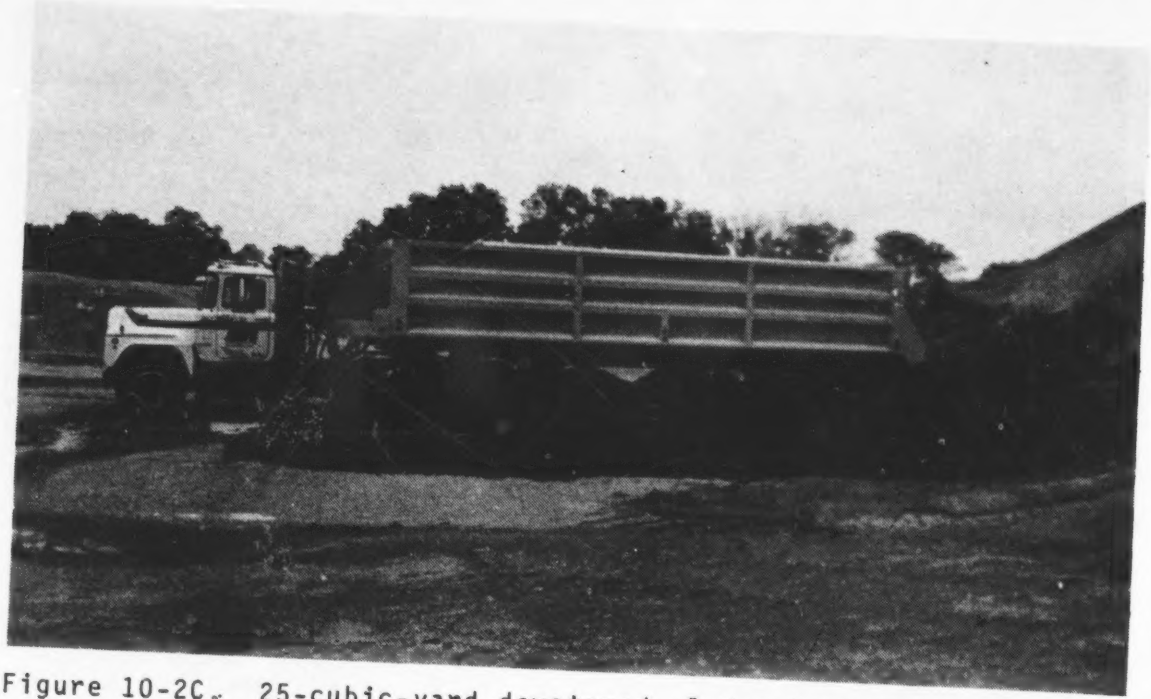


Figure 10-2C. 25-cubic-yard dewatered sludge haul truck (courtesy of Converto Mfg. Co.).

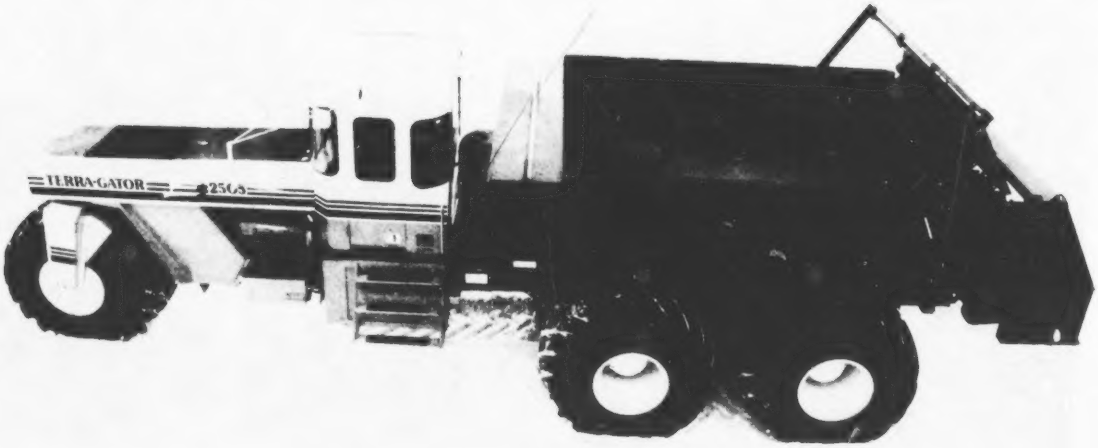


Figure 10-2D. 12-cubic-yard dewatered sludge spreader vehicle (courtesy of Ag-Chem Equipment Co.).

TABLE 10-1
TRUCK OPERATION SUMMARY, LIQUID SLUDGE (6)

Annual Sludge Volume M gal	One-Way Distance (miles)	Trips Per Year			Trucks needed* 8 hr/day operation (22 hr/day operation)**			Truck Use 1,000 miles/yr			Truck Fuel 1,000 gal/year†			Truck Operators 1,000 Man-Hours/Yr#		
		1,200 gal	2,500 gal	5,500 gal	1,200 gal	2,500 gal	5,500 gal	1,200 gal	2,500 gal	5,500 gal	1,200 gal	2,500 gal	5,500 gal	1,200 gal	2,500 gal	5,500 gal
1.5	5	1,250	600	273	1(1)	1(1)	1(1)	13	6	3	2.9	1.3	0.8	1.6	0.8	0.3
	10	1,250	600	273	1(1)	1(1)	1(1)	25	12	6	5.6	2.7	1.6	0.1	1.0	0.5
	20	1,250	600	273	2(1)	1(1)	1(1)	50	24	11	11.1	5.3	3.1	3.2	1.6	0.7
	40	1,250	600	273	2(1)	1(1)	1(1)	100	48	22	22.2	10.7	6.3	4.8	2.3	1.0
	80	1,250	600	273	4(2)	2(1)	1(1)	200	96	44	44.4	21.3	12.6	7.9	3.8	1.7
5	5	4,167	2,000	909	2(1)	1(1)	1(1)	42	20	9	9.3	4.4	2.6	5.3	2.5	1.2
	10	4,167	2,000	909	3(1)	2(1)	1(1)	83	40	18	18.4	8.9	5.1	7.1	3.4	1.5
	20	4,167	2,000	909	4(2)	3(1)	1(1)	167	80	36	37.1	17.8	10.3	10.8	5.2	2.4
	40	4,167	2,000	909	6(3)	3(2)	2(1)	333	160	73	74.0	35.6	20.9	16.0	7.7	3.5
	80	4,167	2,000	909	12(4)	6(2)	3(1)	667	320	145	148.2	71.1	41.4	16.5	12.7	5.8
15	5	12,500	6,000	2,727	5(2)	3(1)	2(1)	125	60	27	27.8	13.3	7.7	15.8	7.6	3.5
	10	12,500	6,000	2,727	7(3)	4(2)	2(1)	250	120	55	55.6	26.7	15.7	11.3	10.2	4.6
	20	12,500	6,000	2,727	12(4)	6(2)	3(1)	500	240	109	111.1	53.3	31.1	32.3	15.5	7.0
	40	12,500	6,000	2,727	18(7)	9(4)	4(2)	1,000	480	218	222.2	106.7	62.3	48.0	23.0	10.5
	80	12,500	6,000	2,727	35(12)	17(6)	8(3)	2,000	960	436	444.4	213.3	124.6	79.5	38.1	17.3
50	5	41,667	20,000	9,091	17(6)	8(3)	4(2)	417	200	91	92.7	44.4	26.0	52.7	25.3	11.5
	10	41,667	20,000	9,091	24(9)	12(4)	6(2)	833	400	182	185.1	88.9	52.0	71.0	34.1	15.5
	20	41,667	20,000	9,091	39(13)	19(7)	9(3)	1,667	800	364	370.4	177.8	104.0	107.7	51.7	23.5
	40	41,667	20,000	9,091	58(24)	28(12)	13(6)	3,333	1,600	727	740.7	355.6	207.7	160.0	76.8	34.9
	80	41,667	20,000	9,091	116(39)	56(19)	26(9)	6,667	3,200	1,455	1,481.6	711.1	415.7	264.9	127.2	57.8
150	5	125,000	60,000	27,273	50(18)	24(9)	11(4)	1,250	600	273	277.8	133.3	78.0	15.81	75.9	34.5
	10	125,000	60,000	27,273	70(25)	34(12)	16(6)	2,500	1,200	546	555.6	266.7	156.0	213.1	102.3	46.5
	20	125,000	60,000	27,273	116(39)	56(19)	26(9)	5,000	2,400	1,091	1,111.1	533.3	311.7	323.1	155.1	70.5
	40	125,000	60,000	27,273	174(70)	84(16)	38(16)	10,000	4,800	2,182	2,222.2	1,066.7	623.4	479.9	230.3	104.7
	80	125,000	60,000	27,273	350(116)	167(56)	76(26)	20,000	9,600	4,364	4,444.4	2,133.3	1,246.9	794.8	381.5	173.4

* 360 days per year.
† Based on fuel use of 4.5 mpg for 1,200 and 2,500 gal trucks, and 3.5 mpg for 5,500 gal truck.
# Based on truck operating hours plus 10 percent.
** Allows average of 2 hours per day for maintenance.
Metric conversions: 1 M gal - 3.78 mil l; 1 mile = 1.609 km; 1 gal = 3.78 l.

TABLE 10-2
TRUCK OPERATION SUMMARY, DEWATERED SLUDGE (6)

Annual Sludge Volume 1,000 cu yd	One-Way Distance Miles	Trips Per Year			Trucks Needed* 8 Hours/Day Operation (24 Hours/Day Operation)**			Truck Use 1,000 Miles/Year			Truck Fuel† 1,000 gal/Year			Truck Operators# 1,000 Man-Hours/Year		
		10 cu yd	15 cu yd	30 cu yd	10 cu yd	15 cu yd	30 cu yd	10 cu yd	15 cu yd	30 cu yd	10 cu yd	15 cu yd	30 cu yd	10 cu yd	15 cu yd	30 cu yd
1.5	5	150	100	50	1(1)	1(1)	1(1)	1.5	1	0.5	0.3	0.2	0.2	0.2	0.1	0.1
	10	150	100	50	1(1)	1(1)	1(1)	3	2	1	0.7	0.4	0.3	0.3	0.2	0.1
	20	150	100	50	1(1)	1(1)	1(1)	6	4	2	1.3	0.9	0.6	0.5	0.3	0.1
	40	150	100	50	1(1)	1(1)	1(1)	12	8	4	2.7	1.8	1.1	0.7	0.4	0.2
	80	150	100	50	1(1)	1(1)	1(1)	24	16	8	5.3	3.6	2.3	1.2	0.6	0.3
5	5	500	333	167	1(1)	1(1)	1(1)	5	3	2	1.1	0.7	0.6	0.6	0.4	0.2
	10	500	333	167	1(1)	1(1)	1(1)	10	7	3	2.2	1.6	0.9	0.9	0.6	0.3
	20	500	333	167	1(1)	1(1)	1(1)	20	13	7	4.4	2.9	2.0	1.3	0.9	0.4
	40	500	333	167	1(1)	1(1)	1(1)	40	27	13	8.9	4.0	3.7	1.9	1.3	0.6
	80	500	333	167	1(1)	1(1)	1(1)	80	53	27	17.8	11.8	7.7	3.2	1.1	1.1
15	5	1,500	1,000	500	1(1)	1(1)	1(1)	15	10	5	3.3	1.2	1.4	12.9	1.3	0.6
	10	1,500	1,000	500	1(1)	1(1)	1(1)	30	20	10	6.7	4.4	2.9	2.6	1.7	0.9
	20	1,500	1,000	500	2(1)	1(1)	1(1)	60	40	20	13.3	8.9	5.7	3.9	2.6	1.3
	40	1,500	1,000	500	3(1)	2(1)	1(1)	120	80	40	26.7	17.8	11.4	5.8	3.8	1.9
	80	1,500	1,000	500	5(2)	3(1)	1(1)	240	160	80	53.3	33.6	22.9	9.5	4.4	3.2
50	5	5,000	3,333	1,667	2(1)	2(1)	1(1)	50	33	17	11.1	7.3	4.9	6.3	4.2	2.1
	10	5,000	3,333	1,667	3(1)	2(1)	1(1)	100	67	33	22.2	14.9	9.4	8.5	5.7	2.8
	20	5,000	3,333	1,667	5(2)	4(2)	2(1)	200	133	67	44.4	19.6	19.1	12.9	8.6	4.3
	40	5,000	3,333	1,667	7(3)	5(2)	3(1)	400	267	133	88.9	59.3	38.0	19.2	12.8	6.4
	80	5,000	3,333	1,667	14(5)	10(4)	5(2)	800	533	267	177.8	118.4	76.3	31.8	11.2	10.6
150	5	15,000	10,000	5,000	6(3)	4(2)	2(1)	150	100	50	33.3	12.2	14.3	19.0	22.7	5.8
	10	15,000	10,000	5,000	9(3)	6(2)	3(1)	300	200	100	66.7	44.4	28.6	25.6	17.1	8.5
	20	15,000	10,000	5,000	14(5)	10(4)	5(2)	600	400	200	133.3	88.9	37.1	38.9	25.9	12.9
	40	15,000	10,000	5,000	21(9)	14(6)	7(3)	1,200	800	400	266.7	177.8	114.3	57.6	38.4	19.2
	80	15,000	10,000	5,000	42(42)	28(10)	4(5)	2,400	1,600	800	533.3	355.6	226.6	95.4	6.36	31.8

* 360 days per year.

† Based on fueluge of 4.5 mpg for 10 and 15 cu yd truck, and 3.5 mpg for 30 cu yd truck.

# Based on truck operating hours plus 10 percent.

** Allows average of 2 hours per day for maintenance.

Metric conversions: 1 cu yd - 0.764 cu m; 1 mile = 1.609 km; 1 gal = 3.78 l.

a specific project. For example, they can be used to quickly compare vehicle needs as a function of whether to truck transport liquid sludge at 5 percent solids or an equivalent quantity of dewatered sludge solids at 25 percent solids. Assuming a liquid sludge quantity of 57 mil l/yr (15 MG/yr), 58,000 mt/yr (64,000 T/yr), and an equivalent quantity of dewatered sludge of 11,470 m^3/yr (15,000 yd^3/yr), 12,000 mt/yr (13,000 T/yr), and a one-way distance of 32 km (20 mi) from treatment plant to application site, Tables 10-1 and 10-2 indicate that for an 8 hr/day operation, approximately six 9,450 l (2,500 gal) tank trucks are necessary to transport the liquid sludge, and only one 11.5 m^3 (15 yd^3) truck is necessary to transport the dewatered sludge. The difference in fuel purchase is 202,000 l/yr (53,500 gal/yr) versus 50,300 l/yr (13,300 gal/yr), and in driver time is 15,500 hr/yr versus 2,600 hr/yr. The above savings in transportation cost of dewatered sludge versus liquid sludge can then be compared to the cost of dewatering the sludge.

The reader should be aware that the above example is obviously highly simplified in that it assumes that the sludge transport operation takes place 360 day/yr, provides an average of only 10 percent plus 2 hr/day for truck idle and maintenance time, and gives no consideration to effects of sludge type upon operating costs at the sludge application site(s).

10.2.2.3 Other Considerations

The haul distance should be minimized to reduce costs, travel time and the potential for accidents en route to the application site(s). Unfavorable topographic features, road load limits, population patterns, etc., may influence routing such that the shortest haul distance is not the most favorable.

Effective speed and travel time can be estimated from the haul distance, allowing for differences in speed for various segments of the route and the anticipated traffic conditions. Periods of heavy traffic should be avoided from a safety standpoint, for efficiency of operation, and for improved public acceptability.

The existing highway conditions must be considered in the evaluation of truck transport. Physical constraints, such as weight, height, and speed limits, may limit truck transport and will definitely influence vehicle and route selection. Local traffic congestion and traffic controls will not only influence routing, but should also be considered in determining the transport operation schedule. Public opinion on the use of local roadways, particularly residential streets may have a significant effect on truck transport operations and routing.

Fuel availability and costs can have a profound impact on the operation and economy of sludge hauling activities. Larger trucks tend to be more fuel efficient than smaller ones. Also, short haul distances over flat terrain will have lower fuel requirements than long distances and hills. Manpower requirements can be determined from the operating schedule.

Truck drivers and mechanics as well as loading and unloading personnel will be required for large sludge hauling operations. Small operations may combine these roles into one or two persons.

The operating program for sludge hauling can be simple or very complex. An example of a simple hauling operation would be a case where all the sludge generated each day is hauled to a dedicated land disposal site and discharged into a large capacity sludge storage facility. In such a simple case, the designer can easily develop an operating schedule for sludge hauling based upon the following:

- Quantity of sludge which will be hauled.
- Average round trip driving time requirement.
- Sludge loading and unloading time requirement.
- Truck maintenance downtime.
- Estimated truck idle time, in addition to maintenance downtime.
- Haul truck capacity.
- Length of working shifts and number of laborers (drivers, etc.) working.
- Safety factor for contingencies, e.g., variations in sludge quantity generated, impassible roads due to weather, etc.

At the opposite extreme from the simple case described above is the development of a complex sludge hauling schedule for an agricultural utilization program involving many privately owned farms. Such a program is complicated by the need to take into account the following additional factors:

- The variation in distance (driving time) from the POTW to the privately owned farms or forests accepting the sludge.
- No sludge storage capacity provided at the sludge application sites.
- Weather, soil conditions, and cropping patterns that severely limit the number of days when and locations where sludge can be applied to farmland.

As an example of the large variations in sludge hauling schedules for a complex agricultural utilization program, Table 10-3 shows the projected monthly sludge distribution for the Madison, Wisconsin, "METROGRO" project. As can be seen, projected sludge volume distribution in the maximum sludge utilization months (e.g., September) is six times that of the miminum sludge utilization months (e.g., February). The designer should provide for the necessary sludge transport, application, etc., equipment and labor to handle the maximum sludge distribution months. This results in under utilization of equipment during the low demand sludge distribution months, as well as the potential problem of shifting employees (e.g., drivers) to other productive work. Some cities have supplemented their forces with private haulers during peak periods to help overcome this problem.

TABLE 10-3
PROJECTED MONTHLY SLUDGE DISTRIBUTION FOR
AGRICULTURAL SLUDGE UTILIZATION PROGRAM, MADISON, WISCONSIN (4)

Month	% of Annual	Gal/Month (x 1,000)	Gal/Day*
January	2.5	1,250	62,500
February	2.5	1,250	62,500
March	2.5	1,250	62,500
April	7.5	3,750	187,500
May	7.5	3,750	187,500
June	5	2,500	125,000
July	10	5,000	250,000
August	12.5	6,250	312,500
September	15	7,500	375,000
October	15	7,500	375,000
November	15	7,500	375,000
December	5	2,500	125,000

* Based on 20-day/month operation.

Metric conversion:

1 gal = 3.78 l

a. Contract Hauling Considerations

Many cities, both large and small, use private contractors for sludge hauling, and sometimes sludge application as well. The economic feasibility of private contract hauling versus use of publically owned vehicles and public employees, should be analyzed for most new projects. If a private contractor is used, it is essential that a comprehensive contract be prepared which considers the total management plan and avoids city liabilty for mistakes by the contractor. As a minimum, the contract should cover the following responsibilities:

- Liability and insurance for equipment and employees.
- Safety and public health protection procedures and requirements.

- Estimated sludge quantities and handling procedures.
- Methods for and responsibility for handling citizen complaints, and other public relations.
- Accident, spill, violation, etc., notification and mitigation procedures.
- Monitoring procedures, record keeping and reporting requirements.
- Responsibility for obtaining and maintaining permits, licenses, and regulatory agency approvals.
- The usual legal document provisions for non-performance relief, termination, etc.

In some instances, sludge is hauled away from the POTW by the user, e.g., farmer, commercial forest grower, etc. Again, the city should obtain competent legal council to avoid potential liability due to negligence by the private user/hauler.

b. Additional Facilities Required for Hauling Operation

Sludge loading facilities at the POTW should be accessible and in a convenient location. Depending on the type of sludge being hauled, hoppers, conveyor belts, or pipelines are needed to load the trucks. Vehicle storage and a maintenance/repair shop may be located at the plant site. Equipment washdown facilities and parking should be nearby.

Similar facilities for truck unloading, etc., may be necessary to the sludge application site(s) and/or sludge storage facility.

10.2.2.4 Cost Estimation Factors

Capital as well as operation and maintenance (O&M) costs for truck transportation are highly variable and dependent on the physical form and quantity of the sludge, hauling distances, labor costs, fuel costs, and other transport rate structure factors (10). Generalized capital and O&M costs include the cost of the vehicles plus the loading and unloading facilities (see Tables 10-4 through 10-6), and can be used to roughly compare costs. Based on the example provided in Section 10.2.2.2, the one-way transportation for 32 km (20 miles) of 57 mil l/yr (15 MG/yr) of liquid sludge can be compared to an equivalent 11,470 m^3/yr (15,000 yd^3/yr) of dewatered sludge. Using Tables 10-4 through 10-6, these estimated costs (1980) are compared below:

- Liquid sludge
  - Capital cost of six 9,450 l (2,500 gal) tank trucks at $65,000 each (Table 10-4), $390,000

TABLE 10-4
CAPITAL AND OPERATING COST OF SLUDGE HAULING TRUCKS

Type of Sludge	Type of Truck	Capacity	Capital Cost x 1,000	Operation Costs* $/mile
Liquid	Tank truck	1,200 gal	35 - 40	0.30
		2,500 gal	60 - 65	0.38
		5,500 gal	90 - 100	0.45
Dewatered	Dump truck, 2 axle	8-10 yd^3	35 - 40	0.30
	Dump truck, 3 axle	10-15 yd^3	65 - 70	0.38
	Dump truck, 3 axle (plus transfer trailer)	15-25 yd^3	80 - 85	0.45
	Dump truck, 3 axle (plus pup trailer)	15-25 yd^3	80 - 85	0.45
	Bottom dump truck (hopper)	25 yd^3	95 - 110	0.54

* Includes operator, fuel, maintenance (labor and supplies) and insurance; does not include loading. Engr. Cons. Cost Index 3237. Cost estimates for mid 1980.

Metric conversions factors:

1 gal = 3.78 l
1 yd^3 = 0.764 m^3
1 mile = 1.609 km.

TABLE 10-5
TRUCK FACILITIES: CAPITAL, OPERATION AND MAINTENANCE DATA, LIQUID SLUDGE*

Item	Annual Sludge Volume, Million Gallons				
	1.5	5	15	50	150
Capital Cost†					
Loading pump, pipe, hose	11,250	11,250	12,750	21,000	30,000
Enclosed truck loading facility#	7,500	10,500	15,000	30,000	37,500
Truck ramp for unloading	22,500	22,500	45,000	75,000	112,500
Unloading truck facility and office	15,000	15,000	22,500	30,000	45,000
Subtotal Capital Costs	56,250	59,250	95,250	156,000	215,000
Operation & Maintenance, $/yr	11,000	14,000	18,000	28,000	41,000

* Assumptions: Pumps and piping sized to fill truck in 20 minutes; use plant sludge storage; gravity unloading at disposal site.

† All costs updated to mid-1980 using Engineering-Construction Cost Index.

# Based on $41/$ft^2$ for office and $25/$ft^2$ for truck enclosure.

Metric conversion factors:

1 mil gal = 3.78 mil l
1 ft^2 = 0.0929 m^2.

TABLE 10-6
TRUCK FACILITIES: CAPITAL, OPERATION AND MAINTENANCE DATA, DEWATERED SLUDGE*

Item	Annual Sludge Volume, 1,000 cu yd				
	1.5	5	15	50	150
Capital Cost†					
Conveyor	15,000	15,000	15,000	30,000	30,000
Loading; hopper	15,000	15,000	15,000	22,500	30,000
Enclosed truck loading facility	7,500	7,500	7,500	15,000	15,000
Truck Ramp	22,500	22,500	22,500	30,000	45,000
Unloading truck facility and office	15,000	15,000	15,000	22,500	37,500
Subtotal Capital Costs	75,000	75,000	75,000	120,000	157,500
Operation & Maintenance, $/yr	7,000	8,000	9,000	17,000	25,000

* Assumptions: Equipment sized to fill truck in 20 minutes; loading hopper sized for one truck load and gravity discharge into truck; gravity unloading at disposal site.

† All costs updated to mid 1980 using Engineer Construction Cost Index.

# Based on $\$41/ft^2$ for office and $\$25/ft^2$ fr truck enclosure.

Metric conversion factors:

$1{,}000\ yd^3 = 764\ m^3$
$1\ ft^2 = 0.0929\ m^2$

- Capital cost of loading and unloading facilities (Table 10-5), $95,250
- Estimated total capital costs of liquid sludge transport, $485,250
- Truck operating costs, $0.24/km ($0.38/mi) (Table 10-4) x 386,000 km (240,000 mi) (Table 10-1), $91,200
- Loading and unloading facility operating cost (Table 10-5), $18,000
- Estimated annual O&M costs for liquid sludge $109,200.

- Dewatered sludge
  - Capital cost of one 11.5 m^3 (15 yd^3) dump truck (Table 10-4), $85,000
  - Capital cost of loading and unloading facilities (Table 10-6) $75,000
  - Estimated total capital cost for dewatered sludge, $160,000
  - Truck operating costs, $0.28/km ($0.45/mi) (Table 10-4) x 64,400 km (40,000 mi) (Table 10-2), $18,000
  - Loading and unloading facility operating costs (Table 10-6), $9,000
  - Estimated annual O&M costs for dewatered sludge, $27,000.

This example indicates that dewatered sludge could be transported for approximately 30 percent of the cost of transporting an equivalent quantity of liquid sludge. Similar analyses could be conducted to approximate relative costs of contract hauling versus public agency purchasing and operating its own vehicles.

10.2.3 Pipeline Transport

Generally, only liquid sludge of 8 percent solids, or less, can be transported by pipeline (17). However, sludges with higher solids concentrations have been pumped, e.g., the city of Seattle, Washington, is reported to be pumping sludge containing up to 18 percent solids. Other important factors include:

- Availability of land for sludge application for projected long-term periods. Pipeline transport is not usually feasible if there are multiple, widely separated land application sites, or if the application site(s) has a short useful life.

- Sufficient sludge volume to justify the high capital costs of a pipeline, pump station(s) and appurtenances. Generally, municipal sewage treatment plants sized below 19 mil l/day (5 mgd) do not generate sufficient sludge volume to justify pipeline transport, unless the distance to the land application site is short, e.g., less than 3 km (2 mi).

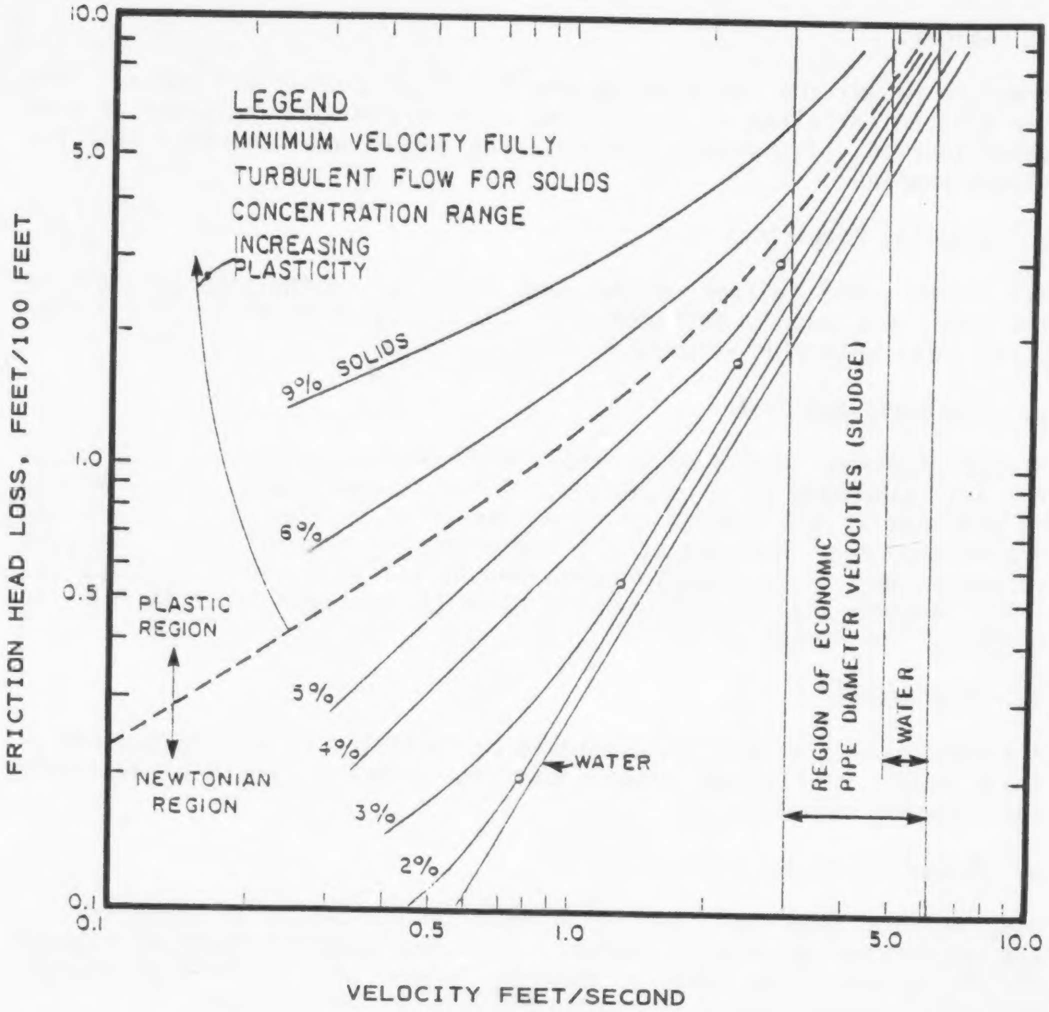
- Existence of a relatively undeveloped and flat pipeline right-of-way alignment between the sewage treatment plant and the land application site. It is very expensive to construct a new pipeline through developed residential/commercial areas or through hilly terrain.

If factors such as those listed above are favorable, sludge transport by pipeline often can be less expensive than truck transport per unit volume of sludge.

10.2.3.1 Pipeline Design

The effect of solids concentration on the sludge flow characteristics is of fundamental importance to economic pipeline design. Digested sludges have been observed to exhibit both newtonian and plastic flow characteristics. Figure 10-3 shows the influence of sludge solids concentrations on minimum velocities required for full turbulent flow. The figure also indicates the frictional head loss and the range of velocities for economical transportation. Below about 5 percent solids, the sludge flow shows newtonian nature, whereas at concentrations above 5 percent, plastic flow characteristics are observed. At solids concentration below 5 percent, the economics of sludge transport will resemble water transport costs with respect to frictional head loss and power requirements. The most cost-effective pipeline design usually assumes operation just within the upper limits for newtonian flow (8) (approximately 5.5 percent solids). An extensive discussion on head loss calculations and equations for sludge pipelines and sludge pumping can be found in Chapter 14 of the Process Design Manual for Sludge Treatment and Disposal (16).

Various pipeline materials are used for transporting sludge. These include steel, cast iron, asbestos-cement, concrete, fiberglass, and PVC. For long-distance, high-pressure sludge pipelines, steel pipe is most commonly used. Corrosion can be a severe problem unless properly considered during design. External corrosion is a function of the pipe material and corrosion potential of the soil, and can be controlled by a suitable coating and/or cathodic protection system. Laboratory tests simulating several digested sludge lines indicated that with proper design only moderate internal corrosion rates should be expected in long-distance pipelines conveying sludge. If most of the grit and other abrasive materials are removed from the digested sludge, wear due to friction is not a significant factor in pipeline design (16).



METRIC CONVERSIONS:

ONE FT/SEC. = 0.3048 m/SEC.

Figure 10-3. Hydraulic characteristics of sludge solids (5).

10.2.3.2 Pipeline Appurtenance Design

Commonly used sludge pipeline appurtenances are briefly discussed below (19)(20). More extensive discussion is found in Chapter 14 of the Process Design Manual for Sludge Treatment and Disposal (16).

a. Gauges

Pressure gauges are installed on the discharge side of all pumps. They may also be installed on the suction side of pumps for purposes of head determination. Protected, chemical-type gauges are generally used for sludge pumping.

b. Sampling Provisions

All sludge pumps, either on the pump itself or in the pipe adjacent to the pump, are usually provided with 2.5 to 3.8 cm (1 to 1-1/2 in) sampling cocks with plug valves.

c. Cleanouts and Drains

Sludge pipelines should be provided with separate cleanouts and drains for easy clearance of obstructions. Blind flanges and cleanouts should be provided at all changes of direction of 45 degrees or more. Valved drains should be provided at all low points in the pipeline. Pressure vacuum relief valves should be provided at all high points in the pipeline. Minimum size at cleanouts is 10 cm (4 in), with 15 cm (6 in) size preferred for access of tools.

d. Hose Gates

A liberal number of hose gates should be installed in the piping, and an ample supply of flushing water under high pressure should be available for clearing stoppages.

e. Measuring Sludge Quantities

Pump running time totalizers provide a simple method of approximating the quantities of sludge pumped. For more sophisticated measurement Venturi meters, flow tubes or magnetic meters with flushing provisions are used. Sludge meters should have provision for bypassing.

10.2.3.3 Pump Station Design

Pump stations used to pump sludge through long-distance pipelines should be carefully designed by experienced engineers. This section is not intended to be a comprehensive guide to design of such stations, but rather to highlight important design considerations, and to make reference to more extensive information. Factors of importance when designing long distance sludge pump station design include:

- Characteristics of the sludge, e.g., type of sludge, solids content, how well stabilized, abrasive particle content, viscosity, etc.
- Quantity of sludge, and type and capacity of sludge storage ahead of the sludge pumps and receiving the sludge at the pipeline terminus.
- Pressure which the pumps must overcome, both pipeline friction loss and static (elevation difference) head.
- Need for standby reliability, i.e., how long can the pump station be out of service for maintenance, power failure, etc., as determined by available sludge storage alternate means of sludge transport, etc.
- Anticipated pump station life.
- Need for future expansion of capacity, e.g., provision of space for future pumps, power supply, piping, etc.
- Ease of operator operation and maintenance.

Each of the above factors is briefly discussed in the following paragraphs.

The sludge most easily pumped long distances has a solids content below 6 percent, is well stabilized (relatively low in volatile solids), is low in abrasive grit, and is free of large particles and stringy material. Sludges possessing other characteristics can be dealt with during design, but will normally cause increased construction, operation, and/or maintenance costs.

The quantity of sludge to be pumped obviously determines the capacity of the pumps and the pump station. Capacity is measured by maximum sludge pumping rate required; therefore, it is desirable to provide for as constant an output pumping rate as possible over long periods of the day. Ideally, the sludge pumps will withdraw the sludge from a large volume storage facility (e.g., a digestor) at a steady rate. If possible, avoid small pump supply storage tanks which require the sludge pumps to frequently start and stop. An additional important point is that the pump supply storage should have a liquid level higher than the elevation of the pump suction intake. Sludge pumps work much more efficiently and reliably if they have a positive suction head.

The pressure which the sludge pumps must overcome is the elevation difference between the pump station and the highest point of the sludge pipeline to the application site, plus the friction loss in the pipe and fittings at the maximum sludge pumping rate. The elevation difference (static head) is fixed by the topography of the pipeline alignment. The head loss due to friction, however, will vary and can be expected to increase with time due to gradual deterioration of the pipeline, buildup of internal sludge deposits, and other factors. The designer, therefore, should provide a safety factor in calculating total pressure loss due to friction in the pipe and fittings. An excellent discussion of sludge pipeline head loss due to friction is found in Chapter 14 of the Process Design Manual for Sludge Treatment and Disposal (16).

Various types of pumps are used to pump sludge. Pumps currently utilized for sludges include centrifugal, torque, plunger, piston, piston/hydraulic diaphragm, ejector and air lift pumps. Table 10-7 presents a matrix which identifies various types of sludges, and provides guidance to the suitability of each type of pump for handling these sludges. See Chapter 14 in the Process Design Manual for Sludge Treatment and Disposal (16) for a more detailed description of each pump type listed above. Centrifugal pumps are commonly selected for long distance sludge pumping because they are more efficient (i.e., use less energy), and can develop high discharge pressures. Centrifugal pumps are not generally used for heavy primary sludges, however, because they cannot handle large or fibrous solids.

The number of pumps installed in a pump station will depend largely on the station capacity and the range in sludge volumes which will be pumped. It is customary to provide a total pumping capacity equal to the maximum expected inflow with at least one of the pumping units out of service. In stations handling small flows two pumps are usually installed, with each pump capable of meeting the maximum inflow rate. For larger stations, the size and number of pumps should be selected so that the range of inflow can be met without starting and stopping pumps too frequently (19).

Proper design must provide a means to add wastewater effluent (or water) to the sludge pumping system for purposes of diluting the sludge and for flushing the pipeline.

It should be assumed that the pump station will occasionally be inoperative due to maintenance, power failure, etc. The designer should provide sufficient storage capacity for sludge and/or standby power to handle at least two days of sludge pumping station shutdown. Emergency tank truck hauling by a private firm is one alternative which could be contracted for beforehand.

Unless the designer is certain that future pump station expansion will not be necessary, space, fittings, etc. should be provided in the pump station for future additions of additional pumping capacity.

TABLE 10-7
APPLICATIONS FOR SLUDGE PUMPS (18)

Pump Type	Miscellaneous Solids				Primary Sludges		Secondary Sludge				Digested Sludge		Lagooned Sludge		Comments
									Thickened Sludge						
	Screenings	Grit	Scum	Septage	Settled Sludge	Thickened Sludge	Trickling Filter	Activated Sludge	Float	Gravity	Mixed <6	Thickened <6	Wet <10	Dry <15	
Centrifugal	1	1	1	1	1	2	4	4	0[a]	1	4	1	4	1	_[b]
Torque Flow	5	4	0	5	4	3	4	4	0[a]	4	4	3	3	0	_[b]; low efficiency
Plunger	0	0	4	4	4	4	4	1	1[c]	4	4	4[d]	4	0	Daily attention
Piston	1	1	1	1	1	1	3	3	3	3	3	3	3	0	High cost[e,f]
Progressive Cavity	4[g]	1	5	4[g]	5	5	5	5	5	5	4	5	5	5	_[h]
Piston/Hydraulic Diaphragm	0	0	0	2	3	3	3	3	3	3	3	3	3	0	
Diaphragm	4	0	4	4	5	5	5	5	5	5	5	4	3	0	
Rotary	0	0	0	0	1	1	1	3	3	3	3	3	3	0	High maintenance cost
Pneumatic Ejector	4[i]	4[i]	3	3	3	3	3	3	3	3	3	3	3	0	
Air Lift	0	2[j]	0	0	4	0	4	4	0	0	0	0	0	0	Low lift
Water	0	1[j]	0	0	0	0	0	0	0	0	0	0	0	0	Low lift

[a] Float may cause air binding.
[b] Varying quality and bead condition impairs positive flow control.
[c] Restricted to low flows.
[d] Maximum 15% solids.
[e] High discharge pressure only.
[f] Should be preceded by grinding.
[g] Large bore pumps may be used with in-line grinding.
[h] Requires special mechanical conditioning for dry sludge food.
[i] Batch pneumatic ejector type recommended.
[j] Short distance only.

Key:
0 - Unsuitable
1 - Use only under special circumstances
2 - Use with caution
3 - Suitable with limitations
4 - Suitable
5 - Best type to use

10.2.3.4 Cost Estimation Factors

Pipeline transportation is a capital intensive system. The cost of the major facilities is directly related to the capacity and length of the pipeline system. Variables affecting the cost of pipeline transportation of sludge include:

- Type of sludge.
- Sludge volume.
- Solids content and viscosity.
- Transportation distance.
- Pipeline alignment.
- Topography of the area through which the pipeline is to be constructed.

Table 10-8 provides estimated pipeline costs relative to pipeline diameter, and Table 10-9 shows the estimated unit cost of different types of crossings that may be encountered when installing pipelines.

Pump station costs were developed from information developed for the EPA (5). Since costs were required for numerous pumping stations with a wide range of capacities, capital cost for each pump station was based on a cost of $110,000 for capacities of up to 25 horsepower and $1,800 for each additional horsepower above 25.

The cost approximations provided for sludge pump stations in the paragraph above, and for pipelines in Tables 10-8 and 10-9, are very simplistic. They can, however, be used to provide initial gross cost comparisons for pipeline transport versus other alternatives for sludge transport. Assume, for example, that the sludge volume generated is 56.7 mil l/yr (15 MG/yr) and the land application site is only 3 km (2 mi) distant. Preliminary engineering calculations indicate a pipeline diameter of 20.3 cm (8 in) and a pump station of 50 horsepower are needed. Using cost noted earlier, it is estimated that the pipeline cost would be 3,219 m x $85/m ($26 x 10,560 ft) = $275,000, and the pump station cost is $110,000 + 24 add. horsepower x $1,800 = $155,000, for a total of $430,000 in capital costs. This cost compares favorably with the cost of truck transport (Tables 10-1 through 10-6), and the engineer should proceed to conduct a more thorough evaluation of the pipeline transport alternative.

TABLE 10-8
ESTIMATED PIPELINE COST (1980) (6)

Pipeline Diameter (in)	Pipeline Costs* ($/LF)
4	22.4
6	23.7
8	26.0
10	28.1
12	30.3
14	34.7
16	41.2
18	47.8
20	64.6

Assumes: No rock and no major problem; one major highway crossing per mile; one single rail crossing per five miles; nominal number of driveways and minor roads ENR-Cons. Cost Index 3237.

* Costs for installed pipelines buried 3 to 6 ft, for 6 to 10 ft depth add 15%, for hard rock excavation add 70%.

Metric conversion factors:

1 in = 2.54 cm
1 ft = 0.3048 m

TABLE 10-9
ESTIMATED PIPELINE CROSSING COSTS (1980) (6)

Crossing	Unit Cost ($)
Highway, two-lane	16,000
Highway, four-lane	19,000
Highway, divided multiple-lane	32,000
Railroad crossing (per track)	12,000
Small river	73,000
Major river	290,000

10.2.3.5 Decision Making Factors

The major factors to consider in the initial evaluation of sludge pipeline transport include:

- Lack of flexibility compared to truck transport. The pipeline has a fixed alignment and terminus. It is necessary that the land application site(s) have a sufficient useful life to justify the capital expense of the pipeline and pump station(s).
- Sufficient sludge volume generation to justify the initial capital cost. Even a small pump station and pipeline will cost at least $400,000 to build. If one or two tank trucks can do the job instead, truck transport will often be more cost effective.
- Need to acquire pipeline right-of-way. Possible pipeline alignments that avoid probable right-of-way easement problems should be evaluated. Condemnation, when necessary, is expensive and time consuming, and may cause problems in community acceptance.

If pipeline transport is selected, the following paragraphs briefly discuss some major design considerations.

a. Alternate Routes Considered

Preliminary planning should be used to reduce the number of potential pipeline routes. Generally, one route will be clearly favorable over the others, however, due to unknown or hidden conditions, a certain amount of flexibility should be maintained until the final design is begun. Crossings can add significantly to the cost of the pipeline and to the complexity of construction. The shortest distance with the least elevation difference and fewest crossings should be the primary goal.

b. Operating Program

A comparison of constant versus variable speed pumps is important in determining the design flow through the pipeline. Variable speed pumps allow for continuous operation and lower storage requirements. Although constant speed pumping will require more storage, for peak flow dampening by equalization, it is usually more energy efficient. The maximum and minimum flow velocities are an important consideration in pipeline design. For sludge transport, 1 mps (3 fps) is a satisfactory value; slower rates can promote solids settling and decomposition, while higher rates can cause scouring and increase head loss. Since pipelines represent a significant investment and have long service lives, they should be sized to permit efficient operation under existing conditions, yet also provide adequate capacity for future growth.

c. Pipeline Design

Pipeline friction losses should be minimized since they contribute significantly to the pumping requirements. Abrupt changes in slope and direction should be minimized. Depending on the nature of the sludge and the characteristics of the soil, corrosion control features should be incorporated in the pipeline design. Air and vacuum relief valves should be provided at high points in the line, drains at low points, clean-outs at abrupt changes in direction, and frequently spaced isolation valves to allow shutdown in case of pipe failure and repair.

d. Pumping Facilities

More than one pump station may be needed if the pipeline distance is long. The number of pump stations should be balanced with the size and number of pumps required to determine the most cost effective combination. Pumps should be appropriate for the type of sludge to be pumped and standby pumping units must be provided.

e. Emergency Operation

Several days storage should be provided in case of equipment failure. Digesters can be used for this purpose, if available. Standby power should normally be provided if there are not two independent sources of electricity to the pump stations. Additional storage may be substituted for standby power under certain conditions, although continuous operation is preferable.

f. Excavation Condition Verification

Field tests should be used to establish or verify the subsurface soil conditions. Borings should be taken after the pipeline route has been established but prior to final design. The field tests should be used to isolate areas where special design considerations are needed. If highly unusual localized conditions exist, they should be avoided, if possible, or additional field tests made.

Existing or other planned underground utilities should be located and field verified, if possible. If exact locations cannot be established, the contractor should be held responsible for locating them during construction.

g. Acquisition of Right-of-Way

Right-of-way easements must be acquired for pipelines on private property. This process should be initiated in the early stages of the project. The preferable method is to obtain access rights on easements owned or controlled by other utilities when possible, or to negotiate with landowners. Condemnation is a lengthy, complex procedure which should be avoided if possible.

10.2.4 Other Transport Methods

Rail car and barge transport are other transport methods for sludge. These methods are normally only considered by large cities for long distance transport to land application sites. In 1982, the city of Chicago operated the only major sludge barging operation in the United States to a land application site, though several large cities still barge sludge for ocean disposal. No cities use rail transport. Because potential systems for using barge or rail transport of sludge are so large, expensive, and unique, this manual provides only a brief discussion of these transport methods in the following sections.

10.2.4.1 Rail Car

Rail transport of sludge is rare and considered only if the quantity of sludge is large, the transport distance is long, and rail lines are in the vicinity of the treatment plant and land application area. Liquid sludge can be hauled by tank cars, while dewatered sludge can be hauled in either open or closed hopper cars. Specially designed tank cars of 75,000 l (20,000 gal) capacity are available for transporting liquid sludge. The hauling of liquid sludge is similar to moving any other liquid commodity by rail. However, due to the properties of the liquid sludge, problems could arise from the separation of liquid and solid phases during transit. Hauling dewatered sludge by rail closely resembles hauling coal or ore (8). Bridging of dewatered sludge may be a problem. Hopper cars that could be used for dewatered sludge transport typically have a capacity of about 76 m^3 (100 yd^3). For a more detailed discussion on rail transport, refer to Chapter 14, Section 14.3.2, in the Process Design Manual for Sludge Treatment and Disposal (16).

10.2.4.2 Barge Transport

Barges can also be used for hauling liquid or dewatered sludge where suitable waterways exist. Although barging is a slow means of transportation, it offers high capacity with low cost primarily due to the large volumes hauled and low investment. For more information on different types and sizes of barges and the number of barges required to haul different sludge quantities, refer to Chapter 14, Section 14.3.3 in the Process Design Manual for Sludge Treatment and Disposal (16).

10.2.4.3 Cost Estimation Factors

10.2.4.3.1 Rail Car

Cost information for different types of rail cars, including operating costs are presented in Chapter 14, Section 14.3.2, in the Process Design Manual for Sludge Treatment and Disposal (16).

10.2.4.3.2 Barging

Costs for barge hauling can be significantly influenced by:

- Volume hauled.
- Tug speed.
- Travel distance.
- Existing water conditions.

See Process Design Manual for Sludge Treatment and Disposal (Chapter 14, Section 14.3.3) (16) information for detailed barging costs.

10.3 Sludge Storage

10.3.1 Storage Requirements

Sludge storage is necessary to accommodate fluctuations in sludge production rate, breakdowns in equipment, agriculture cropping patterns, and adverse weather conditions which prevent immediate sludge application to the land. Storage can potentially be provided at either the treatment plant, the land application site(s), or both. Chapter 15 in the Process Design Manual for Sludge Treatment and Disposal (16) presents methods for estimating sludge storage capacity and describes various storage facilities. In addition, Chapter 9 of this manual includes sections covering sludge storage volume calculations and preliminary storage facility design considerations for the dedicated land disposal option, which may be helpful in the design of any large volume, open lagoon type sludge storage facility.

Long-term storage of sludge in lagoons for 5 years or more is not uncommon. When the lagoons are near capacity, the city contracts with a private contractor to remove the sludge and utilize it in a land application program. Several private firms specialize in this service, and supply all of the labor, equipment, and public relations required.

10.3.2 Storage Capacity

10.3.2.1 Sludge Volume and Characteristics

Sludge characteristics vary with sludge origin, retention time (sludge age), and the type of sludge treatment. Data on the typical quantities of sludge produced from various treatment processes are presented in Chapter 3, Table 3-4, in the EPA Process Design Manual for Municipal Sludge Landfills (18). The different types of storage, the methods by which the sludge can be stored, and applicable detention times for each type of storage are summarized in Chapter 15, Table 15-1, in the Process Design Manual for Sludge Treatment and Disposal (16).

10.3.2.2 Climate Considerations in Evaluating Sludge Storage

The designer should consider all the following factors:

- Historical precipitation and temperature records for the application site area.
- Regulatory agency requirements pertinent to the land application of sludge on frozen, snow covered, and/or wet soil.
- The ability of the sludge application equipment being used to operate on wet or frozen soil.
- The drainage characteristics of the application site(s) as they affect the time required after precipitation to dry sufficiently to accommodate equipment.

Clearly, the sludge storage capacity required due to climate considerations is greatly influenced by site specific factors. A review of land application system designs in the United States indicates that sludge storage volume provided ranges from a minimum of 30 days in hot, dry climate up to 200 days in cold, wet climates.

The U.S. EPA conducted a computer analysis of approximate storage requirements for wastewater to land application systems in the United States (10), as shown in Figure 10-4. No similar analysis exists (1982) for sludge application systems. Figure 10-4 is included in this manual to show general regional variations in storage requirements due to climate. For most sludge application systems, the actual storage requirement will usually exceed the days shown in Figure 10-4.

10.3.2.3 Sludge Application Scheduling Considerations in Evaluating Sludge Storage

The majority of existing sludge land application systems in the United States are applying sludge to privately owned land. This requires a flexible schedule to conform with local farming practices. Scheduling limitations will result from cropping patterns, and typically the designer will find that much of the agricultural land can only receive sludge during a few months of the year. (The Madison, Wisconsin, program [Table 10-3] applies over 68 percent of its sludge to farmland during the 5-month period from July through November.)

The sludge application to forest sites should be scheduled to conform with tree grower operations and the annual growth-dormant cycle of the tree species.

Sludge application for reclamation of disturbed land must be scheduled to conform to vegetative seeding and growth patterns and also to private landowners operational schedules.

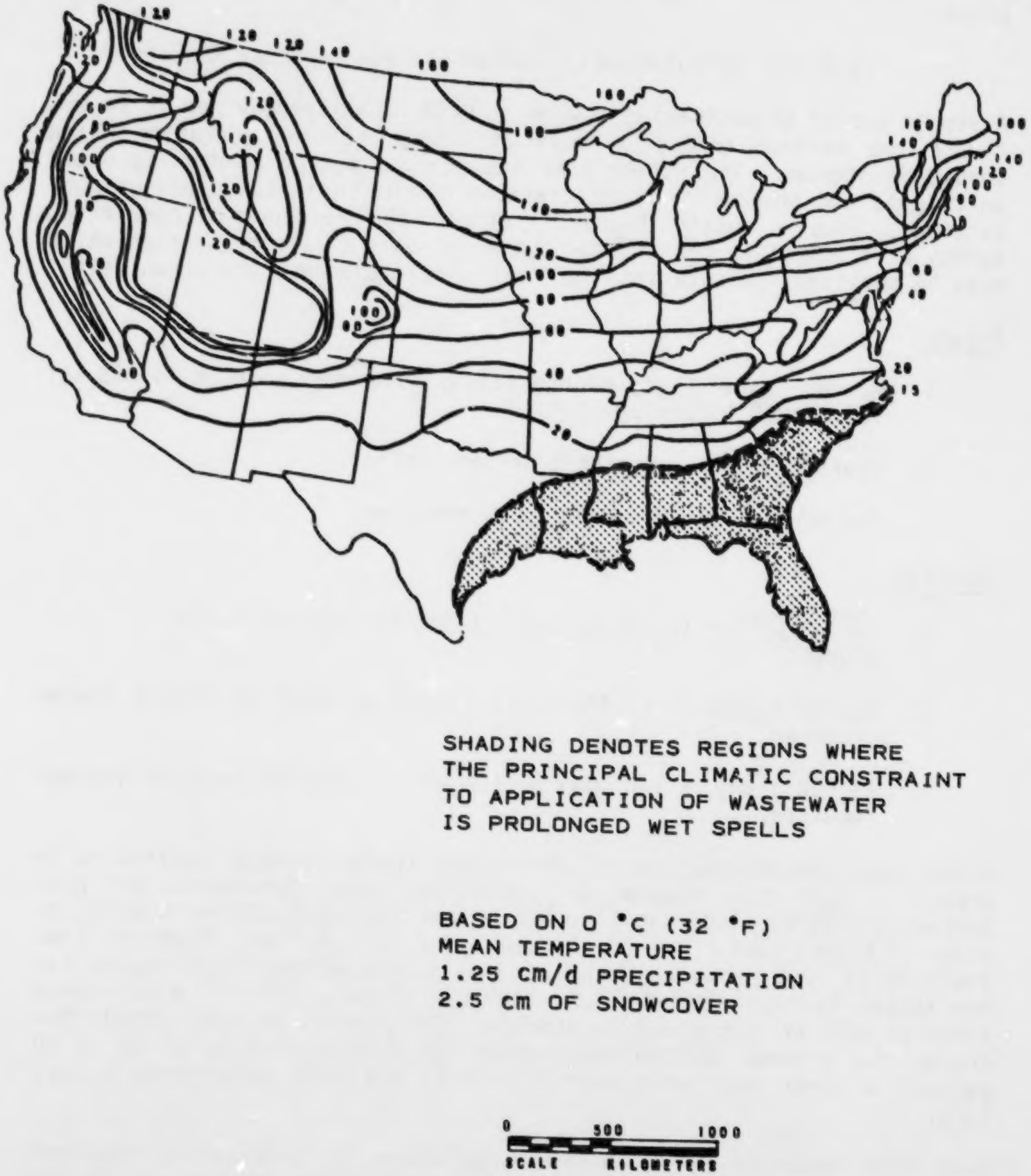


Figure 10-4. Storage days required as estimated from the use of the EPA-1 computer program for wastewater-to-land systems. Estimated storage based only on climatic factors.

The dedicated land disposal option is usually only limited by climate considerations and soil conditions, and not by other scheduling limitations.

10.3.2.4 Calculation of Sludge Storage Capacity Required

A simple method of estimating sewage storage capacity required is to estimate the maximum number of days of sludge volume generation which should be stored. The estimate of the maximum number of days is based on climate and scheduling considerations discussed in the previous subsections, plus a safety factor. Often, the responsible regulatory agency will stipulate the minimum number of days of sludge storage which must be provided. Calculations for this simple approach are shown below:

Assume

1. Average rate of dry sludge solids generated by POTW is 589 kg/day (1,300 lb/day).
2. Average sludge contains 5 percent solids.
3. One hundred days storage to be provided.

Solution

1. $\frac{589 \text{ kg/day}}{0.05}$ = 11,778 kg/day (26,000 lb/day) of liquid sludge.
2. 11,778 kg/day = 11,778 l/day (3,118 gal/day) of liquid sludge produced.
3. 11,788 l/day x 100 days = 1.2 mil l (312,000 gal) of storage required.

A more sophisticated method of calculating sludge storage required is to prepare a mass flow diagram of cumulative sludge generation and projected cumulative sludge application to the land application site(s), as shown in Figure 10-5. The figure uses data from Madison, Wisconsin (see Table 10-3), and shows that the minimum sludge storage requirement for the system is approximately 1.2×10^6 gal (4.54×10^6 l), which represents 84 days of sludge volume storage. The project designer should increase the minimum storage requirement by a safety factor of 20 to 50 percent to cover years with unusual weather and other contingencies factors.

Even more accurate approaches can be taken to calculating required sludge storage volume. For example, if open lagoons are used for sludge storage, the designer can calculate volume additions resulting from precipitation, and volume subtractions resulting from evaporation from the storage lagoon surface.

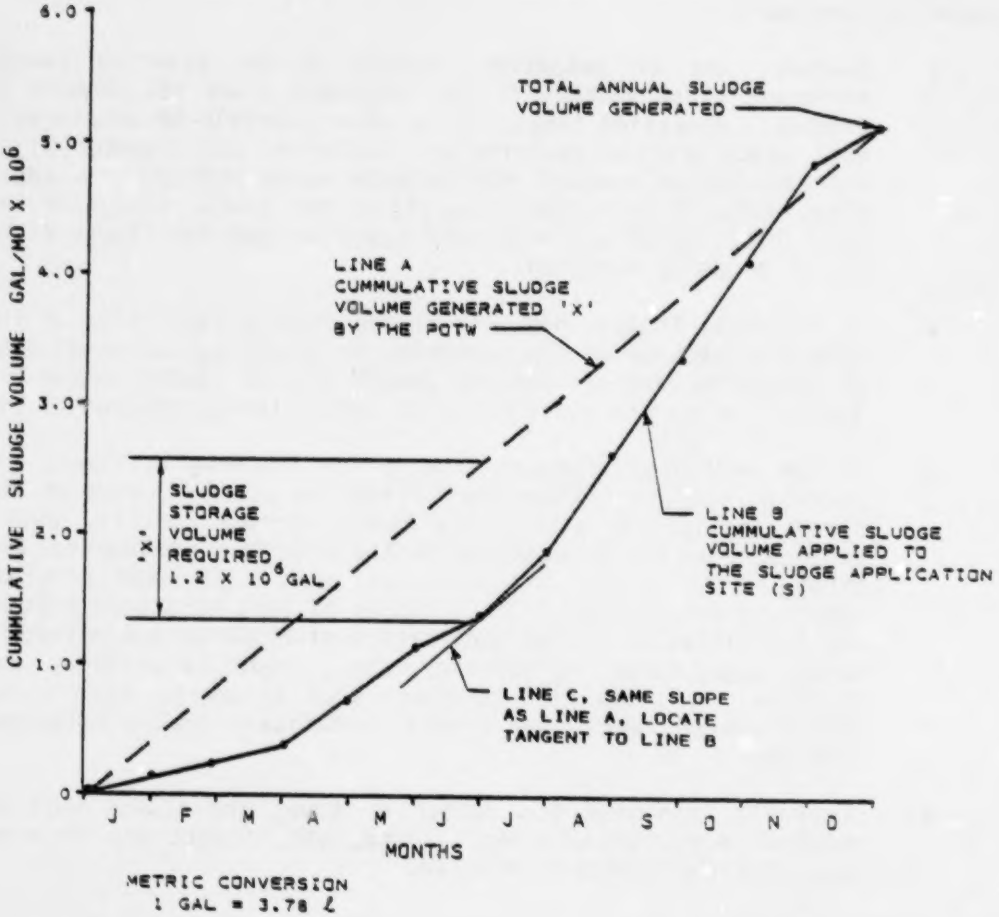


Figure 10-5. Example of mass flow diagram using cumulative generation and cumulative sludge application to estimate storage requirement.

10.3.3 Location of Storage

Chapter 15, pages 15-4 through 15-58, of the EPA Process Design Manual for Sludge Treatment and Disposal (16), contains a comprehensive discussion of sludge storage options and should be consulted for more details. In general, the following factors in siting sludge storage facilities should be considered:

- Maximize use of potential storage in the existing sewage treatment plant units. If the treatment plant has aerobic or anaerobic digestion tanks, it is often possible to obtain several weeks storage capacity by separating the digestor(s) to increase solids content and increase surge storage. In addition, older POTW's often have phased out tanks, sludge drying beds, etc., which are idle, and could be used for sludge storage if properly modified.
- If possible, locate long-term sludge storage facilities at the POTW site because of the proximity of operating personnel ease of vandalism control, and the possibility of sludge volume reduction during storage which will reduce transportation costs.
- If the dedicated disposal site option is being utilized, the long-term sludge storage facilities are often located at the sludge application site. The sludge storage facility should be located as far as possible on the site from residential and other public access areas, since occasional odor problems should be anticipated. The location of long-term sludge storage facilities at sludge application sites which are privately owned, e.g., farms, forestlands, etc., should be avoided. Experience has shown that problems such as odors, controlling public access, etc., may create significant public relations problems.
- Generally, minimize the number of times the sludge must be handled, e.g., transferred, stored, etc. Costs are incurred each time the sludge is handled.

10.3.4 Storage Design

Storage capacity can be provided by:

1. Stockpiles.
2. Lagoons.
3. Tanks, open top or enclosed.
4. Digestors.

10.3.4.1 Stockpiles

Stockpiling is a process for the temporary storage of sludge that has been stabilized and dewatered or dried to a concentration (about 20 to

60 percent solids) suitable for mounding with bulldozers or loaders. The sludge is mounded into stockpiles 2 to 5 m (6 to 15 ft) high, depending on the quantity of sludge and the available land area. Periodic turning of the sludge helps to promote drying and maintain aerobic conditions. The process is most applicable in arid and semiarid regions, unless the stockpiles are covered to protect against rain. Enclosure of stockpiles may be necessary to control runoff. For more information on stockpiling as a method of storage, see Chapter 15, Section 15.3.2.3, in the Process Design Manual for Sludge Treatment and Disposal (16).

10.3.4.2 Lagoons

Lagoons are usually the least expensive way to store sludge. With proper design, lagoon detention will also provide additional stabilization of the sludge and reduce pathogens. Several types of lagoons have been used for sludge storage, including:

- Facultative Sludge Lagoons.
- Anaerobic Liquid Sludge Lagoons.
- Aerated Storage Basins.
- Drying Sludge Lagoons.

For details of each, see Chapter 15 in the Process Design Manual for Sludge Treatment and Disposal (16).

10.3.4.3 Tanks

Various types of tanks can be used to store sludge. In most cases, tanks are an integral part of the sludge treatment processes of the POTW and their design includes storage capabilities. The three types discussed in Chapter 15 of the Process Design Manual for Sludge Treatment and Disposal (16) include:

- Imhoff and Community Septic Tanks.
- Holding Tanks.
- Unconfined Hoppers and Bins.

10.3.4.4 Treatment Plant Digestor Capacity

Many sewage treatment plants do not have separate sludge retention capacity, but rely on portions of the digestor volume for storage. When available, an unheated sludge digestor may provide short-term storage capacity. In anticipation of periods when sludge cannot be applied to the land, digestor supernatant withdrawals can be accelerated to provide storage for several weeks of sludge volume (17).

10.3.5 Cost Estimation Factors

Detailed cost information on the different types of storage facilities previously discussed can be found in the Process Design Manual for Sludge Treatment and Disposal (16).

10.4 Sludge-to-Land Application Methods

10.4.1 Current Status

The technique used to apply sludge to the land can be influenced by the means used to transport the sludge from the POTW(s) to the land application site(s). Commonly used methods include the following:

- Same transport vehicle both hauls sludge from the POTW(s) to application site(s) and applies sludge to land.
- One type of transport vehicle, usually with a large volume capacity, hauls sludge from the POTW(s) to the application site(s). At the application site(s) the sludge haul vehicle transfers the sludge either to an application vehicle or into a storage facility, or both.
- Sludge is pumped and transported by pipeline from the POTW(s) to a storage facility at the application site(s). Sludge is subsequently transferred from storage facility(s) to sludge application vehicle(s).

As a broad classification, sludge application methods involve either surface or subsurface application. Each has advantages and disadvantages which are discussed in the following subsections. In all of the application techniques, the sludge eventually becomes incorporated into the soil, either immediately by mechanical means or over time by natural means.

As a second broad classification, sludge is applied either in liquid form or in dewatered form. Methods and equipment used are different for land application of these two sludge forms, and again each has advantages and disadvantages which are highlighted in the specific following subsections.

Application of sludge to land in liquid form is attractive because of its simplicity. Dewatering processes are not required, and the liquid sludge can be readily pumped. Liquid sludge application systems include:

- Vehicular surface application
  - Tank truck spreading
  - Tank wagon spreading.
- Subsurface application
  - Plow furrow or disking methods
  - Subsurface injection.

- Irrigation application
  - Spray application
  - Gravity flooding.

10.4.2 Vehicular Application of Liquid Sludge

10.4.2.1 Vehicle Types Available

Tables 10-10 and 10-11 describe the methods, characteristics, and limitations of applying liquid sludge by surface application and subsurface injection, respectively.

10.4.2.2 Vehicular Surface Application

Liquid sludge can be surface spread with application vehicles equipped with splash plates, spray bars, or nozzles.

Uniform application is the most important criterion in selecting which of the three attachments are best suited to an individual site. Figure 10-6 depicts a tank truck equipped with a splash plates. Figure 10-7 depicts a tank truck with a rear mounted "T" pipe. For these two methods, application rates can be controlled either by valving the manifold or by varying the speed of the truck. However, a much heavier application will be made from a full truck than from a nearly empty truck or wagon unless the speed of the truck or wagon advancing across the field is steadily decreased to compensate for the steadily decreasing hydraulic head (1). Figure 10-8 depicts a spray nozzle mounted on a tank truck. By spraying the liquid sludge under pressure, a more uniform coverage is obtained.

10.4.2.3 Subsurface Application

Soil incorporation (subsurface application) of liquid sludge has a number of advantages over surface application. Potential odor and other nuisance problems can generally be avoided, nitrogen is conserved since ammonia volatilization is minimized, and public acceptance may be better. However, soil incorporation has a number of potential disadvantages as well, compared to liquid sludge surface application: (1) it may be more difficult to achieve even distribution of the sludge, (2) for agricultural use the annual periods when sludge can be applied are restricted to before planting and after harvesting crops, and (3) higher fuel consumption (cost) are required for sludge application. Soil incorporation of sludge can be done in a number of ways. The principal methods are subsurface injection and plow or disc cover.

Figures 10-9 and 10-10 illustrate equipment specifically designed for subsurface injection of sludge. This equipment includes tank trucks with special injection equipment attached. Tanks for the trucks are generally available with 6,000, 7,500, and 11,000 l (1,600, 2,000, and

TABLE 10-10
SURFACE APPLICATION METHOD AND EQUIPMENT FOR LIQUID SLUDGES (4)

Method	Characteristics	Topographical and Seasonal Limitations
Tank truck	Capacity 500 to more than 2,000 gallons; it is desirable to have flotation tires; can be used with temporary irrigation set-up; with pump discharge can achieve a uniform application rate.	Tillable land; not usable at all times with row crops or on very wet ground.
Farm tank wagon	Capacity 500 to 3,000 gallons; it is desirable for wagons to have flotation tires; can be used with temporary irrigation set-up; with pump discharge can achieve a uniform application rate.	Tillable land; not usable at all times with row crops or on very wet ground.

Metric conversion factor:

1 gal = 3.78 l.

TABLE 10-11
SUBSURFACE APPLICATION METHODS, CHARACTERISTICS, AND LIMITATIONS FOR LIQUID SLUDGES (9)

Method	Characteristics	Topograhic and Seasonal limitations
Flexible irrigation hose with plow or disc cover	Use with pipeline or tank truck with pressure dos-discharge; hose connected to manifold discharge on plow or disc.	Tillable land; not usable on very wet or frozen ground.
Tank truck with plow or disc cover	500-gal commercial equipment available; sludge discharge in furrow ahead of plow or disk mounted on rear on 4-wheel-drive truck.	Tillable land; not usable on very wet or frozen ground.
Farm tank wagon with plow or disc cover	Sludge discharged into furrow ahead of plow mounted on tank trailer; application of 170 to 225 wet tons/ac; or sludge spread in narrow band on ground surface and immediately plowed under; application of 50 to 120 wet tons/acre.	Tillable land; not usable on very wet or frozen ground.
Subsurface injection	Sludge discharge into channel opened by a chisel tool mounted on tank truck or tool bar; application rate 25 to 50 wet tons/ac; vehicles should not traverse injected area for several days.	Tillable land; not usable on very wet or frozen ground.

Metric conversion factors:

1 gal 3.78 l
1 ton/ac = 2.24 mt/ha.

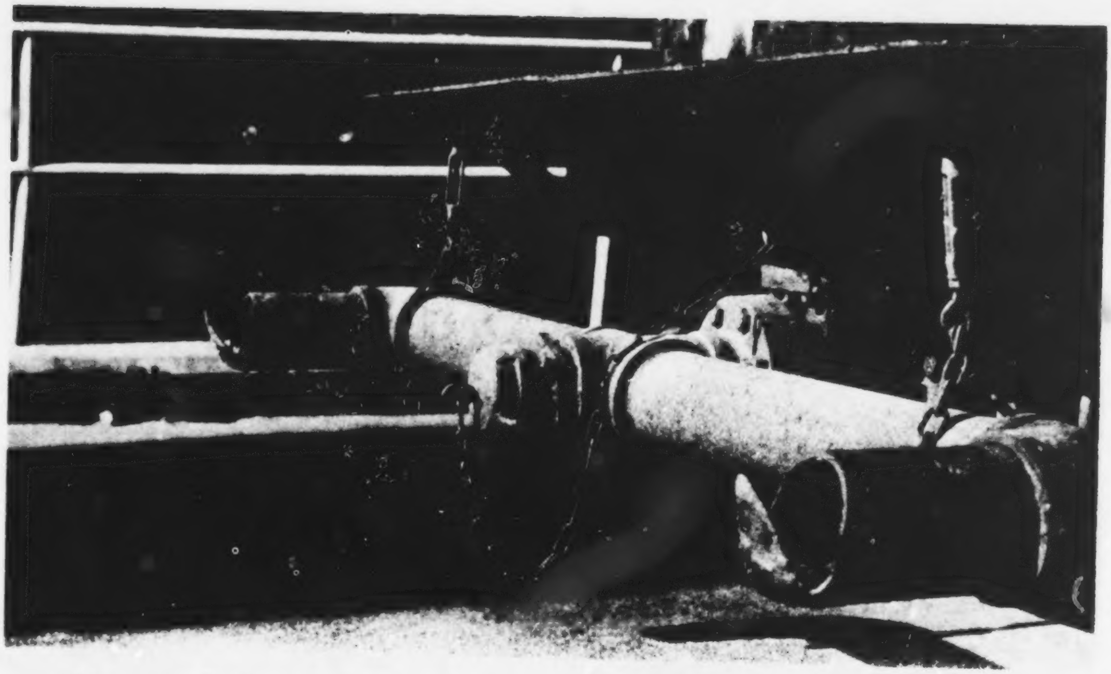


Figure 10-6. Splash plates on back of tanker truck (17).

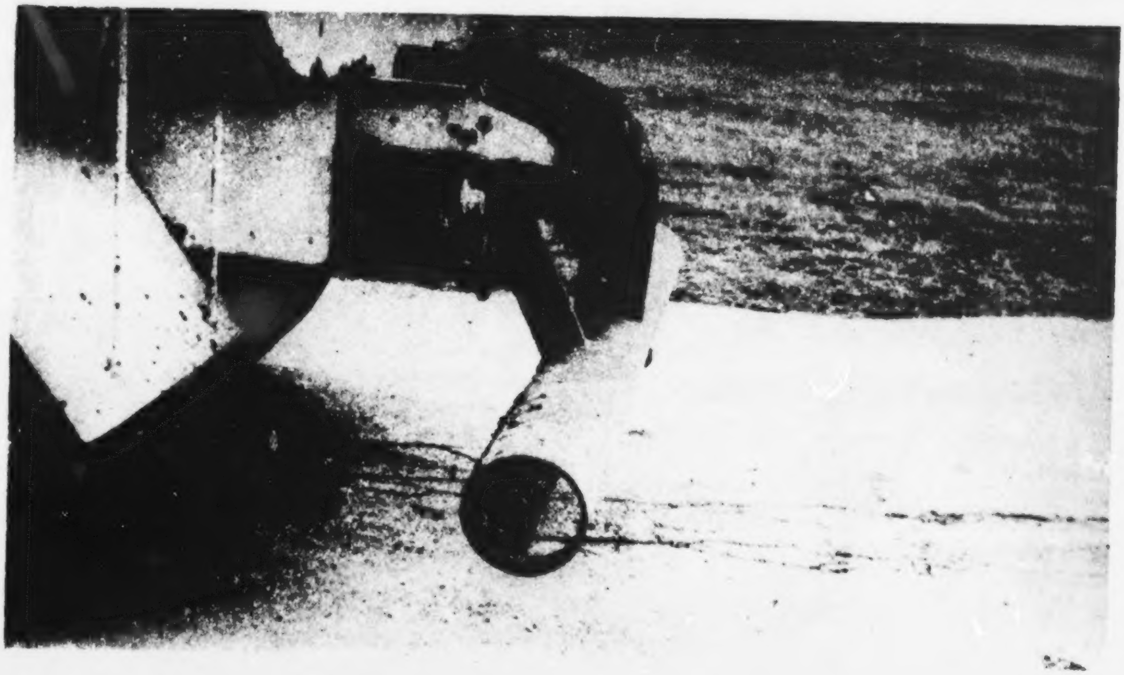


Figure 10-7. Slotted T-bar on back of tanker truck (17).

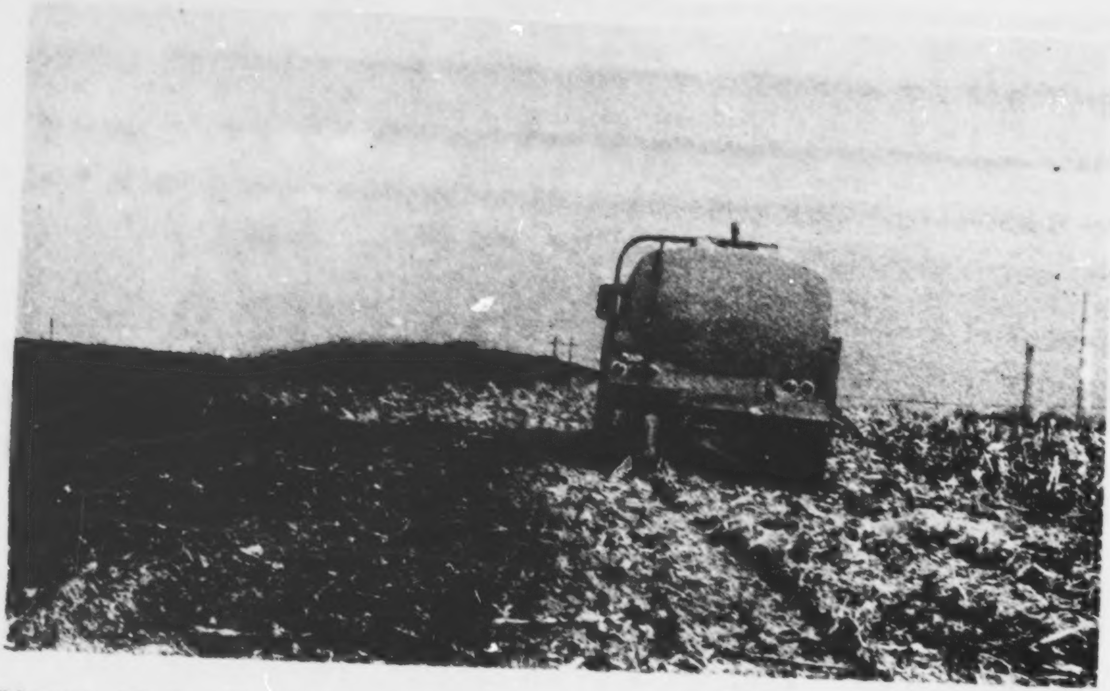


Figure 10-8. Tank truck with side spray nozzle for liquid sludge surface application (17).

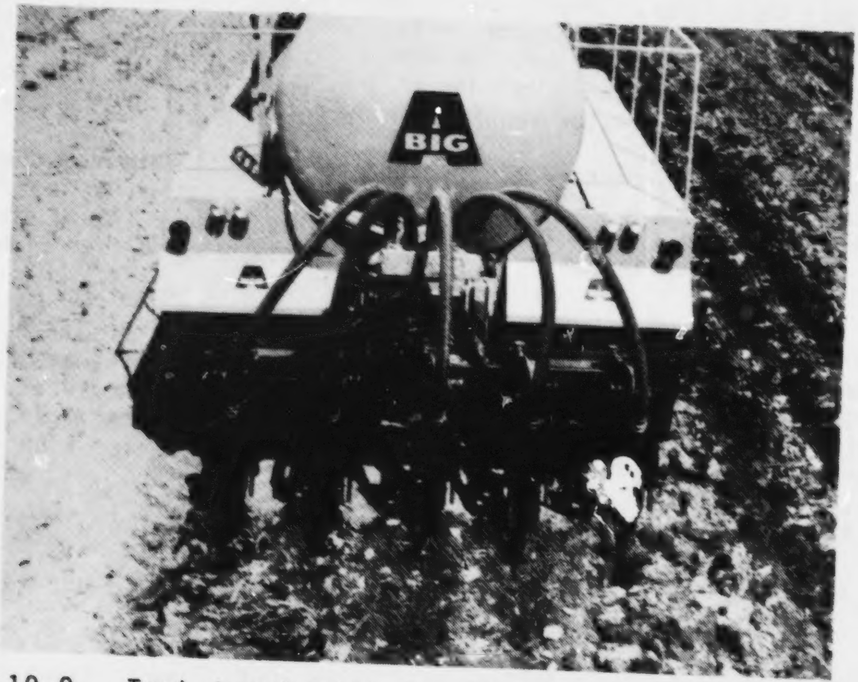


Figure 10-9. Tank truck with liquid sludge tillage injectors (courtesy of Rickel Mfg. Co.).

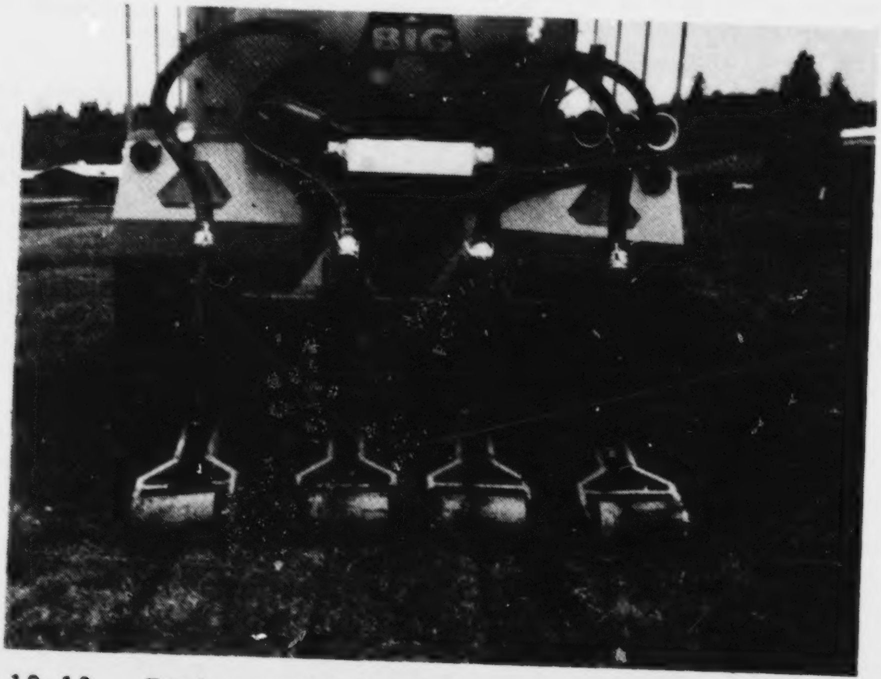


Figure 10-10. Tank truck with liquid sludge grassland injectors (courtesy of Rickel Mfg. Co.).

3,000 gal) capacities. Figure 10-11 shows another type of unit, a tractor with a rear mounted injector unit. Sludge is pumped from a storage facility to the injector unit through a flexible hose attached to the tractor. Discharge flow capacities of 570 to 3,800 l/min (150 to 1,000 gpm) are used. The tractor requires a power rating of 40 to 60 hp.

It is usually not necessary to incorporate (inject) liquid sludge into the soil when the sludge is applied to existing pasture or hay fields; however, injection systems are available that can apply liquid sludge to these areas with a minimum of crop and soil disturbance (see Figure 10-10).

The plow or disc cover method involves discharging the sludge into a narrow furrow from a wagon or flexible hose linked to a storage facility through a manifold mounted on the plow or disc, which immediately covers the sludge with soil. Figure 10-12 depicts a typical tank wagon with an attached plow. These systems seem to be best suited for high loading rates, i.e., a minimum of 3.5 to 4.5 mt/ha (8 to 10 dry T/ac) of 5 percent slurry (9).

10.4.3 Vehicle Application of Dewatered Sludge

10.4.3.1 Vehicle Types Available

Spreading of dewatered sludge is similar to surface application of solid or semisolid fertilizers, lime, or animal manure. Dewatered sludge cannot be pumped or sprayed; spreading is done by box spreaders, bulldozers, loaders or graders, and then plowed or disked into the soil. The box spreader is most commonly used, with the other three equipment items generally being used only for high sludge application rates.

The principal advantages of using dewatered sludge are reduced sludge hauling and storage costs, and the ability to apply higher sludge application rates with one pass of the equiment. Potential disadvantages of applying dewatered sludge are that, generally, substantial modification of conventional spreading equipment is necessary to apply sewage sludge, and more operation and maintenance is generally incurred in equipment repairs as compared to many liquid sludge application systems. Table 10-12 describes methods and equipment for applying dewatered sludge to the soil.

TABLE 10-12
METHODS AND EQUIPMENT FOR APPLICATION OF DEWATERED SEMISOLID AND SOLID SLUDGES

Method	Characteristics
Spreading	Truck-mounted or tractor-powered box spreader (commercially available); sludge spread evenly on ground; application rate controlled by PTO and/or over-the-ground speed; can be incorporated by disking or plowing.
Piles	Normally hauled by dump truck; spreading and leveling by bulldozer or grader needed to give uniform application.

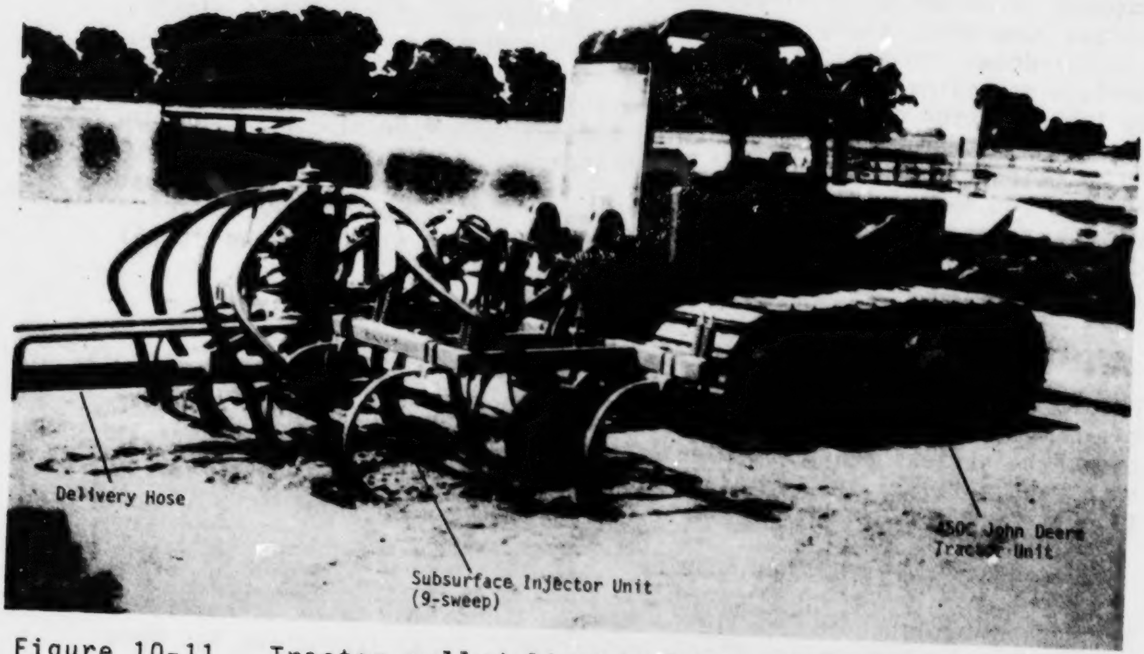


Figure 10-11. Tractor pulled liquid sludge subsurface injection unit connected to delivery hose (courtesy Briscoe Maphis Co.).

Figure 10-12A. Tank wagon with sweep shovel injectors (4).

Figure 10-12B. Sweep shovel injectors with covering spoons mounted on tank wagon (4).

10.4.3.2 Surface Application

Figures 10-13 and 10-14 illustrate the specially designed trucks used to spread dewatered sludge. For small quantities of dewatered sludge, tractor-drawn conventional farm manure spreaders may be adequate (10). Surface spreading of dewatered sludge on tilled land is usually followed by incorporation of the sludge in the soil. It is not usually necessary to incorporate dewatered sludge with the soil when the sludge is applied to existing pasture or hay fields. Standard agricultural discs or other tillage equiment pulled by a tractor or bull dozer can incorporate liquid or dewatered sludge with soil. There are three different types: disk tillers, disk plows, and disk harrows (Figures 10-15 and 10-16) (13).

10.4.4 Cost Estimation Factors

Precise capital and operation and maintenance costs are difficult to estimate due to site specific variables. To obtain current cost information, the various equipment manufacturers should be contacted. Typical cost ranges (1982) of liquid and dewatered sludge hauling and spreading trucks are shown in Table 10-13.

10.4.5 Irrigation Application

Irrigation application of liquid sewage sludge has been accomplished using spray irrigation and flood irrigation. Spray irrigation has been used primarily for forest land sludge applications and occasionally for application of sludge to dedicated land disposal sites. Flood irrigation of sludge has generally not been successful, and is usually discouraged by regulatory agencies.

10.4.5.1 Spray Application

Spray irrigation application has been used to disperse liquid sludges on clearcut openings, dedicated land disposal sites, and in forest stands. Liquid sludges are readily dispersed by use of properly designed equipment. Sludge solids must be relatively small and uniformly distributed throughout the sludge in order to achieve uniform application and to avoid system clogging. A typical spray application system consists of the use of a rotary sprayer (rain gun) to disperse the liquid sludge over the application site. The sludge, pressurized by a pump, is transferred from storage to the sprayer via a pipe system. Design of the system can be portable or permanent and either moving or stationary. Available spray irrigation systems include (10):

1. Solid set, both buried and above ground.
2. Center pivot.
3. Side roll.
4. Continuous travel.
5. Towline laterals.
6. Stationary gun.
7. Traveling gun.

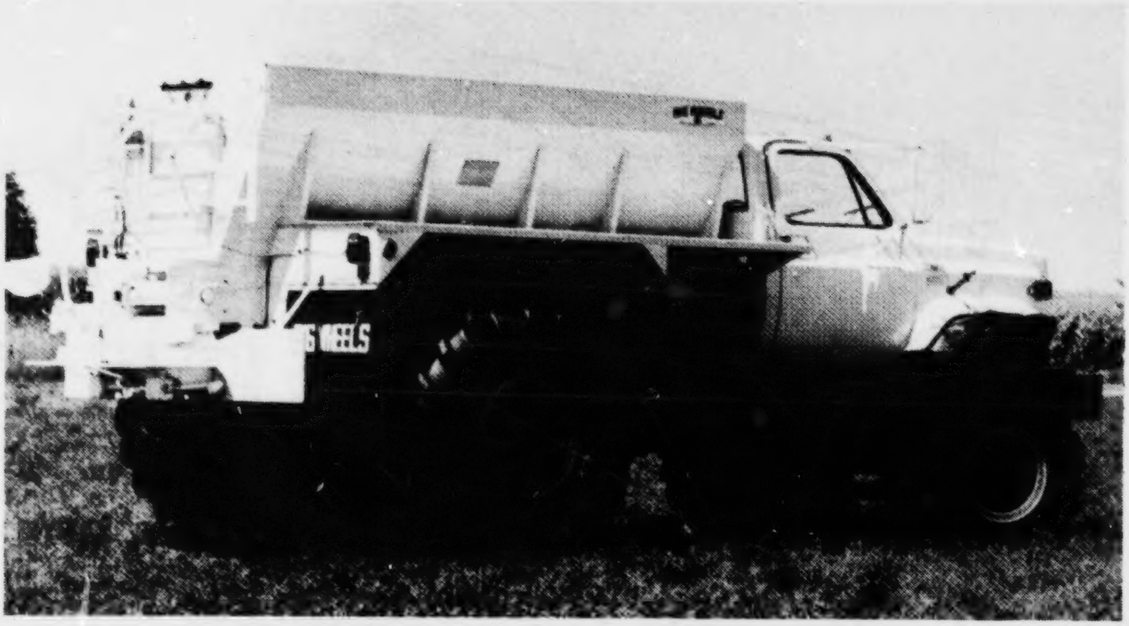


Figure 10-13. 7.2 cubic yard dewatered sludge spreader (courtesy of Big Wheels Inc.).

Figure 10-14. Large dewatered sludge spreader (courtesy of BJ Mfg. Co.).

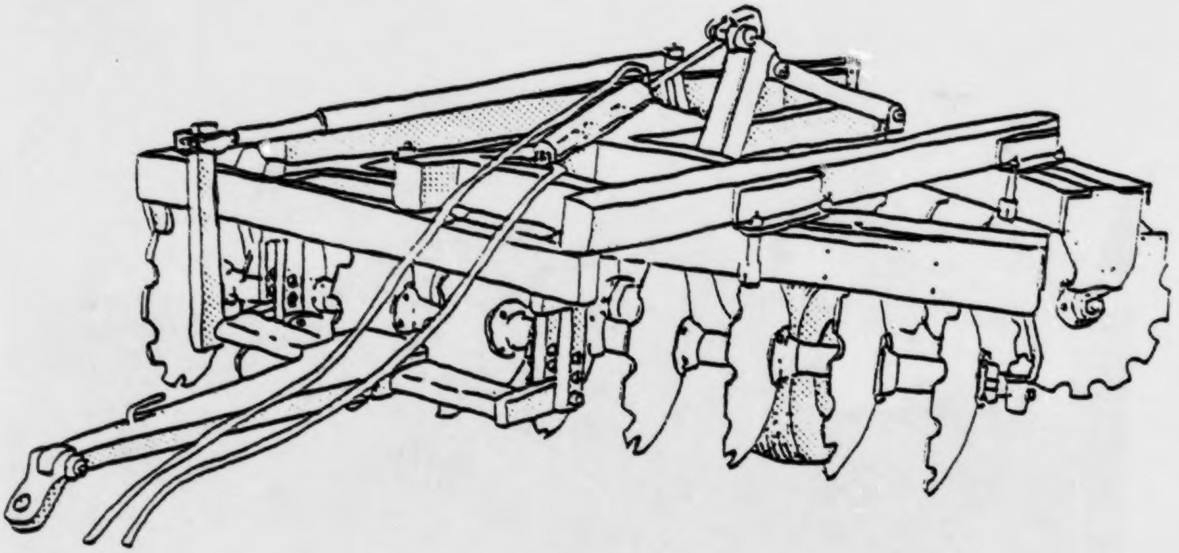


Figure 10-15. Example of disc tiller.

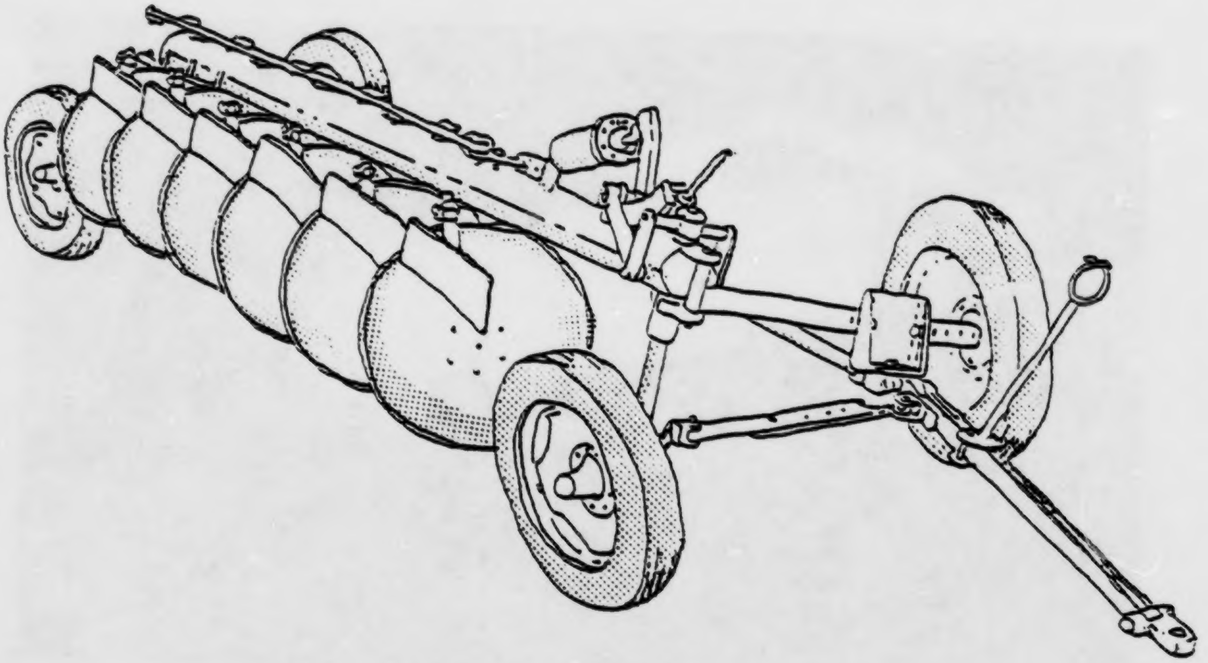


Figure 10-16. Example of disc plow.

TABLE 10-13
APPROXIMATE 1982 LIST PRICES FOR SLUDGE HAULING AND SPREADING TRUCKS
(TELEPHONE SURVEY, DECEMBER 1982)

LIQUID SLUDGE

Capacity (Gal)	Base Price Range ($1,000)	Price Range with Typical Sludge Accessories ($1,000)
1,600	60-80	65-85
2,000(a)	80-90	85-100
3,000	90-105	95-115
3,500	110-130	120-140
4,000	120-140	130-150
6,000	130-160	140-175

DEWATERED SLUDGE

Capacity (yd^3)	Base Price Range ($1,000)	Base Price Range with Typical Sludge Accessories ($1,000)
7	60-70	70-80
9	70-80	80-90
10	80-100	90-110
15	100-130	115-145
17	130-150	145-165
18	150-160	165-175
25	150-180	170-200
36	180-210	200-230

(a) The city of Seattle took bids for a specially equipped sludge application truck for forest application in late 1982. Tank capacity is 2,000 gallons and truck is equipped with flotation tires, articulated chassis, sludge spray cannon with 120-ft range, and dozer blade. Cost was $160,000.

Metric conversions:

1 gal = 3.78 l
1 yd^3 = 0.765 m^3
1 ft = 0.305 m

The utility of these systems within the application site depends upon the application schedule and management scheme utilized. All the systems listed, except for the buried solid system are designed to be portable. Main lines for systems are usually permanently buried. This provides protection from freezing weather and runover by heavy vehicles.

The proper design of sludge spray application systems requires through knowledge of the commercial equipment available, and its adaptation to use with liquid sludge. Few sludge spray irrigation systems are in use, and these are generally associated with dedicated land disposal sites. It is beyond the scope of this manual to present engineering design data, and it is suggested that qualified irrigation engineers and experienced irrigation system manufacturers be consulted.

Figures 10-17, 10-18, and 10-19 illustrate a few of the systems listed. Table 10-14 presents a cost comparison of the most widely used spray irrigation systems, in terms of characteristics important to sludge application.

TABLE 10-14
APPROXIMATE CAPITAL COST OF DIFFERENT
SPRINKLER SYSTEMS (12)

Type of System	Approximate Cost ($/ac)†	Size of Single System (ac)	Labor Required (hr/ac Irr.)
Portable solid set*	540 - 1,200	No limit	0.20 - 0.50
Buried solid set	540 - 1,350	No limit	0.05 - 0.10
Side wheel roll	130 - 400	20 - 80	0.10 - 0.30
Traveling gun	160 - 340	40 - 100	0.10 - 0.30
Center pivot	240 - 470	40 - 160	0.05 - 0.15

* Towline lateral system is same, except that field shape is not as flexible.

† Does not include cost of water supply, pump, power unit, and mainline.

xx Costs are updated to 1980.

Metric conversion factor:

ac = 0.4047 ha.

10.4.5.2 Gravity Irrigation

In general, land application by gravity flooding of sludge has not been successful where attempted, and is discouraged by regulatory agencies and experienced designers. Problems arise from (1) difficulty in achieving uniform sludge application rates, (2) clogging of soil pores, and (3) tendency of the sludge to turn septic with resulting odors.

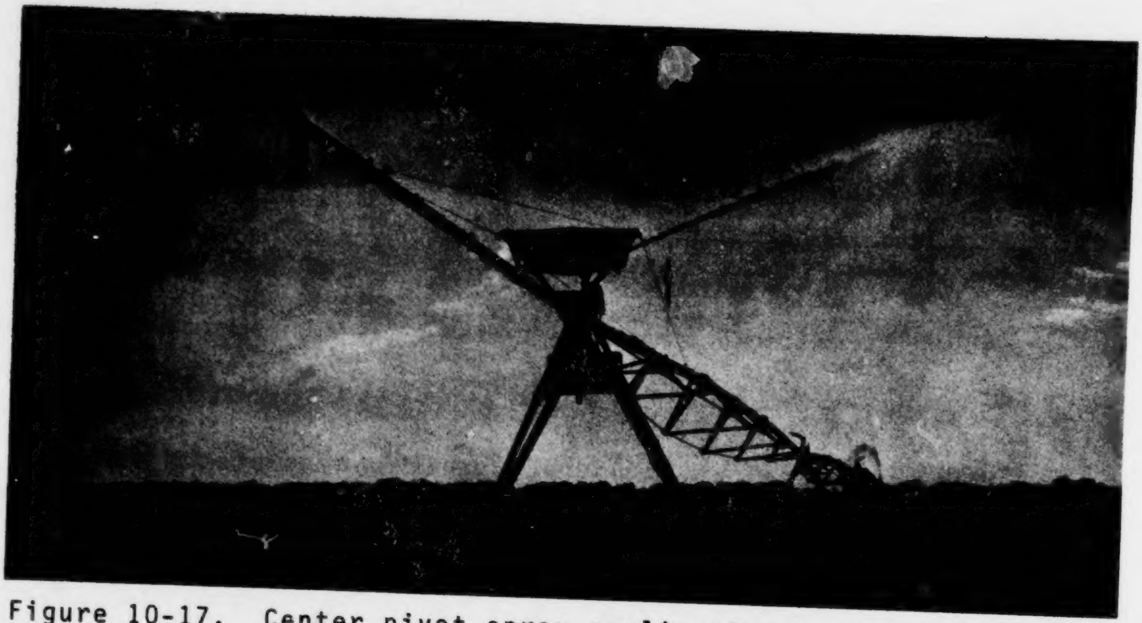


Figure 10-17. Center pivot spray application system (courtesy of Valmont Ind. Inc.).

Figure 10-18. Traveling gun sludge sprayer (courtesy of Lindsay Mfg. Co.).

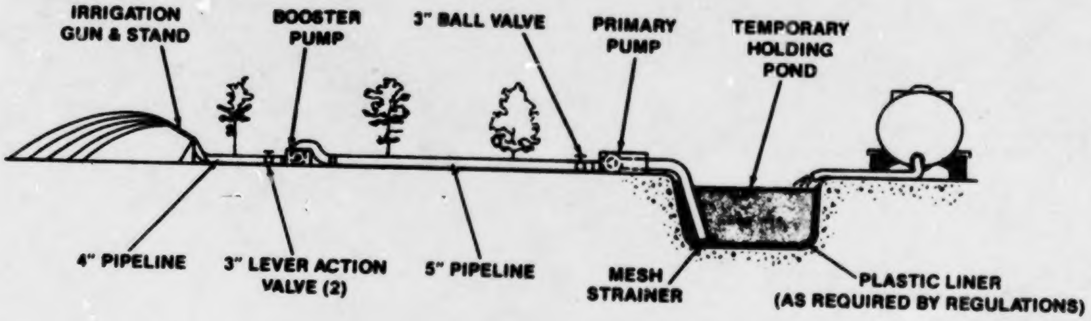


Figure 10-19. Diagram of liquid sludge spreading system in forest land utilizing temporary storage ponds (19).

10.5 Site Preparation

10.5.1 General

In general, for agricultural sludge utilization systems where sludge is applied to privately owned farms at low agronomic application rates, site modifications are not typically cost effective. At forested systems, there is usually much more forest land available within the local area than is needed for sludge application, so unsuitable land can be avoided, not modified.

In the case of sludge utilization for disturbed land reclamation, it is common that extensive site grading and soil preparation is necessary. However, these site preparation costs are usually borne by the land owner (e.g., mining company, ore processor, etc.), and not by the municipality (see Chapter 8 for discussion).

Extensive sludge application site modification and improvement costs may be acceptable to the municipality only where the dedicated land disposal site option is being utilized for high rate sludge application over long periods of time, since the costs can be amortized over many years of application site life.

The site improvements for DLD systems will require:

- Topographic map, scale of 1:1200 or less, with contour intervals of 0.6 m (2 ft) or less.
- Soil map.
- Drainage map.
- Ground water or piezometric contour map.
- Drawing showing location of existing structures.
- Knowledge of design criteria imposed by (1) regulatory requirements (2) proposed sludge transport and application methods, (3) size and location of buffer areas needed, (4) application site sludge storage requirements, and (5) off-site access roads.

10.5.2 Grading

The purpose of establishing surface grades is to ensure that runoff water and/or liquid sludge do not pond. Emphasis in planning is given to filling depressions with soil from adjoining ridges and mounds. If an excessive amount of filling is required for low places, or if sufficient soil is not readily available, field ditches can be installed and the surfaces warped towards them (14). In areas with little or no slope, grades can be established or increased by grading between parallel ditches with cuts from the edge of one ditch and fills from the next.

Terraces may be needed to protect lower lands from surface flows. These are generally dug across a slope, or at the toe of a slope with the borrow material diked on the lower side for efficient use of the material. Diversion terraces are generally graded and grass covered so that the collected water may be delivered at non-erosive flows to a control discharge point.

10.5.3 Subsurface Water Control

See Chapter 9, Section 9.7.7, for information on subsurface drain construction which may be used to prevent ground water pollution.

10.5.4 Cost Estimation Factors

Site preparation costs are very site-specific, and the information provided in this section is only presented as an example.

10.5.4.1 Dike Costs

The following assumptions were made for the designed dike:

(a) Dikes consist of a 1.2 m (4 ft) wide clay core surrounded by granular borrow.

(b) Borrow is available on site, while clay is purchased off-site.

(c) Compaction in 20 cm (8 in) lifts.

(d) Material amounts to be purchased are measured as installed and compacted volumes.

(e) Dike is 1.2 m (4 ft) high with 2:1 side slopes.

Construction cost for a dike such as described above (1982 dollars) would range from $13 to $20 per linear m ($4 to $6 per linear ft) of dike length in most parts of the country. In terms of area, if dikes are constructed at 18 m (60 ft) intervals, the cost of dike construction is about $8,650/ha ($3,500/ac).

10.5.4.2 Dike Costs

The following assumptions were made for this example:

Assumptions:

1. Borrow pit for soil material is located on site.
2. Compaction in 30 cm (12 in) lifts to 95 percent compaction.
3. Berm is 1 m (3 ft) high with 2:1 side slopes.

The cost (1980 dollars of berm as described would be about $3.50/m^3 (2.70/yd^3), or $52.50 per linear m ($16 per linear ft) of berm.

10.5.4.3 Site Grading Costs

The following assumptions are made for site grading:

1. All soil moved is on site.
2. Minimum number of trees.
3. No rock blasting necessary.
4. Average of 3,000 m^3/ha (1,593 yd^3/ac) of dirt is moved and graded, e.g., an average of 0.3 m (1 ft) of depth.

The costs (1980 dollars) for clearing and grubbing will be approximately $2,220/ha ($900/ac). Grading will cost approximately $1.30/$m^3$ ($1.20/$yd^3$), or $4,700/ha ($1,900/ac) using the assumptions listed above. Total rough estimate costs for grading is $6,900/ha ($2,800/ac). If the topography is highly irregular, grading costs can greatly exceed this estimate. For example, a city in Texas spent ten times the estimate above to grade a dedicated land disposal site located on drastically disturbed, highly eroded soil.

10.6 Supporting Facilities Design

The cost of supporting facilities, such as permanent all-weather access roads, fences, etc., can normally only be justified for high rate sludge application sites which will be used over a long project life. They are rarely applicable to privately owned agricultural sludge utilization sites.

10.6.1 Access Roads

A permanent road should be provided from the public road system to dedicated land disposal sites. For large sludge application sites, the roadway should be 6.5 to 8 m (20 to 24 ft) wide for two-way traffic; for smaller sites, a 5 m (15 ft) wide road should suffice. To provide all weather access, the roadway, as a minimum, should be gravel surfaced. Asphalt pavement is preferable. Grades should not exceed equipment limitations. For loaded vehicles, uphill grades should be less than 7 percent.

10.6.2 Site Fencing and Security

Access to dedicated land sludge disposal sites should be limited to one or two entrances that have gates which can be locked when the site is unattended. Depending on the topography and vegetation on the site and adjoining areas, entrance gates may suffice to prevent unauthorized vehicular access. At some sites, it is necessary to construct peripheral fences to restrict trespassers and animals.

Fencing requirements are influenced by the relative isolation of the site. Sites close to residences require fencing. Facilities that are in relatively isolated rural areas, may require a less sophisticated type of fence or only fencing at the entrance and other places to keep unauthorized vehicles out.

To discourage vandalism and trespassing, a 2 m (6 ft) high chain link fence topped with barbed wire guard is desirable. To screen the facility from view, a wood fence or hedge may be used (18).

10.6.3 Equipment and Personnel Buildings

At larger facilities or where climates are extreme, buildings may be necessary for office space, equipment, and employee facilities. Since application sites may be operated year around, some protection from the elements for the employees and equipment may be necessary. Sanitary facilities should be provided for both site and hauling personnel. At smaller facilities where buildings cannot be justified, trailers may be warranted (18).

10.6.4 Lighting and Other Utilities

If application operations occur at night, portable lighting should be provided at the operating area. Lights may be affixed to haul vehicles and on-site equipment. These lights should be situated to provide illumination to areas not covered by the regular headlights of the vehicle.

If the facility has structures (employee facilities, office buildings, equipment repair or storage sheds), or if the access road is in continuous use, permanent security lighting may be needed.

Larger sites may need electrical, water, communication, and sanitary services. Remote sites may have to extend existing services or use acceptable substitutes. Portable chemical toilets can be used to avoid the high cost of extending sewer lines; potable water may be trucked in; and an electrical generator may be used instead of having power lines run on site.

Water should be available for drinking, dust control, washing mud from haul vehicles before entering public roads, and employee sanitary facilities. Telephone or radio communications may be necessary since accidents or spills can occur that necessitate the ability to respond to calls for assistance (18).

10.6.5 Cost Estimation Factors

10.6.5.1 Road Construction Costs

Road construction costs vary widely depending upon local conditions. Typical 1980 costs for rough estimating purposes are given below.

- Cleaning and grubbing, \$1.72/m^2 (\$0.16/ft^2).
- Grading and compacting subbase, \$2.15/m^2 (\$0.20/ft^2).
- Base Material, in-place, 30 cm (12 in), \$6.45 m^2 (\$0.60/ft^2).
- Wear coarse material, 10 cm (4 in) crushed stone, \$3.00/m^2 (\$0.28/ft^2).
- Bituminous paving, 7.5 cm (3 in), \$5.38/m^2 (\$0.80/ft^2).
- Miscellaneous drainage culverts, etc., \$5.38/m^2 (\$0.50 ft^2).

Typical 1980 costs for an all weather road are the total of the above, which equals \$27.55/m^2 (\$2.50/ft^2). If a 8 m (24 ft) wide all weather road is constructed, the cost is aproximately \$186,000/km (\$300,000/mi). A 5 m (15 ft) wide all weather road is approximately \$124,000/km (\$200,000/mi).

A less expensive, gravel only road can be constructed for approximately 40 percent of the above costs for a bituminious paved road.

10.6.5.2 Fence Construction Costs

Typical 1980 unit costs of installed fences are approximately as follows:

- Two m (6 ft) high chain link with barb wire topping strands is \$33/linear m (\$10/linear ft), plus \$900 for each gate.
- Other types of fences range in cost from \$16 to \$40/linear m (\$5 to \$12/linear ft).

10.6.5.3 Lighting Costs

Typical 1980 lighting costs for fixed pole mounted lights of various types are as follows:

- Mercury vapor, \$415 for 400 watt; \$520 for 1000 watt.
- Metal halide, \$455 for 400 watt; \$595 for 100 watt.
- High pressure sodium, \$490 for 400 watt; \$720 for 1000 watt.

10.6.5.4 On-Site Structure Costs

Typical 1980 structural costs for rough estimation purposes are as follows:

- Office type structure, \$590/m^2 (\$55/ft^2).
- Maintenance/warehouse type structure, \$330/m^2 (\$31/ft^2).

Trailers cost approximately \$430/m^2 (\$40/ft^2), or rent for approximately \$43/m^2/month (\$0.40/ft^2/month).

10.6.5.5 Ground Water Monitoring Costs

In many cases, regulatory agencies will require monitoring of ground water quality beneath and adjacent to sludge to land application sites. Typical 1980 costs for monitoring well construction are as follows:

- Well material and construction, \$106/m (\$32/ft) of depth.
- Sampling pump and accessories, \$1,700 each.
- Typical 1980 costs for sampling and analysis are approximately \$200/sample.

A typical monitoring installation may have four monitoring wells 9 m (30 ft) deep, and be sampled four times annually. In such a situation, monitoring capital cost would be approximately \$10,600.

10.6.5.6 Other Monitoring Costs

Monitoring costs involved in sludge, soil, and plant analyses can be estimated by contacting local commercial laboratories that can conduct the analyses required.

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CHAPTER 11

OPERATION AND MANAGEMENT

11.1 General

For all systems, a planned operation and management program should be prepared (many state regulatory agencies require such a plan) and responsibility clearly defined for its implementation. Essential elements of the operation and management program include the following:

- Operations at the POTW to ensure that the treated sludge is adequately stabilized and monitored to meet the requirements for land application.
- Flexible scheduling of sludge transport, storage, and application activities to allow for both the need of the POTW to remove sludge, and the ability to apply the sludge to the land application site(s).
- Design, operation, management, and maintenance of the sludge transport system to minimize potential nuisance and health problems. Included should be an in-place procedure for rapid response to accidents, spills, and other emergency conditions arising during routine sludge transport operations.
- Design, operation, management, and maintenance of the sludge application site(s) and equipment to minimize potential nuisance and health problems. Where privately owned and operated land is involved (e.g., farms, commercial forest land, mined lands, etc.), the owner/operator is a key participant in the overall application site management and operation program.
- Monitoring and Reporting - monitoring of sludge generation and analyses of sludge, soil, plant, surface water, and ground water as needed for compliance with stipulations, standards, and regulatory requirements. The extent of monitoring required will vary greatly depending on the sludge application rate and location.
- Recordkeeping - adequate documenting of program activities, monitoring, etc.
- Health and Safety - necessary steps must be routinely employed to protect the general public, operations personnel, etc.

11.2 Nuisance Issues

Minimizing adverse aesthetic impacts of a sludge land application system will aid in maintaining public acceptance of the project. Continuous efforts should be made to avoid or reduce nuisance problems associated with sludge hauling, application, and related operations (13). Potential nuisances of concern include noise, odor, spillage, mud, and dust.

11.2.1 Odor

All sludge management systems must consider objectionable odor as a potential problem. Objectionable odors could result in an unfavorable public reaction and reduced acceptance of land application options. Potential for odors can be reduced or eliminated:

- Proper sludge stabilization at the POTW, and a defined procedure for managing sludge which is not properly stabilized, e.g., additional treatment, alternate disposal means, etc.
- Incorporation of sludge as soon as possible after delivery and application to the site.
- Daily cleaning (or more frequently, if needed) of trucks, tanks, and other equipment.
- Avoiding sludge application to waterlogged soils, or other soil or slope conditions which would cause ponding or poor drainage of the applied sludge.
- Use of proper sludge application rates for application site conditions.
- Avoiding or limiting the construction and use of sludge storage facilities at the land application site(s), or designing and locating the sludge storage facilities to prevent odor problems. Experience has shown that sludge storage facilities are a major cause of odor problems at land application sites.
- Subsurface injection of sludges. After subsurface injection, the soil should not be disturbed for several weeks, if possible; a second tillage operation a few days later may cause odors.
- Isolation of the sludge application site(s) from residential, commercial, and other public access areas.

Prevention of odor problems using the recommendations listed above is important to public acceptance of land application programs. If, and when, odor problems resulting in citizen complaints do occur, the project management should have established procedures for correcting the problems and responding to complaints.

11.2.2 Spillage

All trucks involved in handling sludge over highways and streets should be designed to prevent sludge spillage. Liquid sludge tankers generally do not present a problem. For sludge slurries (10 to 18 percent solids) specially designed haul vehicles with anti-spill baffles have been effectively employed. Sludge spillage on-site can generally also be best controlled using vacuum transfer systems. If mechanical or human errors during transport or at the application site do result in spillage of sludge, cleanup procedures should be employed as soon as possible.

11.2.3 Mud

Both tracking of mud from the field on to highways, and field or access road rutting by sludge transport or applicator equipment are nuisance concerns. Mud can be a particularly severe problem in areas with poor drainage, but can occur at any site during periods of heavy rain or spring thaws. To minimize these problems, the following management steps should be considered.

- Choose all-weather site access roads or modify access roads with gravel or other acceptable weight-bearing material.
- Use vehicles with flotation tires.
- Use vehicles with smaller capacity or temporarily reduce volume of sludge being hauled.
- Mud tracked on roads should be removed.
- Vehicles should be washed down regularly when moving between sites to prevent tracking of mud on highways. This process also improves the public image of sludge hauling and handling systems and improves continued community acceptance.

11.2.4 Dust

Dust movement off-site is enhanced by wind or the movements of haul vehicles and equipment. To minimize dust generation, access roads may need to be graveled, paved, oiled, or watered.

11.2.5 Road Maintenance

The breakup of roads by heavy sludge hauling vehicles can be a problem, particularly in northern climates, and can cause public complaints. Project management should make provisions to repair roads or to have a fund available to help finance cost of road repairs resulting from project activity.

11.2.6 Selection of Haul Routes

Routes for sludge haul trucks should avoid residential areas to prevent nuisance caused by truck and air brake noise, dangers to children, and complaints because of frequency of hauling.

11.3 Safety Concerns

The safety of everyone involved in a sludge application program is of paramount importance. This concern encompasses individuals working directly with sludge (POTW personnel, sludge haulers, farmers, heavy equipment operators, etc), as well as persons living or working near an application site, or who are visiting the site.

Safety features should be incorporated into every facet of the system design. Certain practices should be followed routinely to assure safe working conditions. An official operations plan should be adopted, which contains specific safety guidelines for each operation and feature of the system.

The operation of sludge hauling and application equipment presents the greatest potential for accidents. Equipment should be operated only by fully trained and qualified operators. Regular equipment maintenance and operational safety checks should be conducted.

The stability of the soil can present a potential safety problem, particularly when operating large equipment. Vehicles should approach disturbed or regraded sites, muddy areas, or steep slopes cautiously to prevent tipping or loss of control.

As with any construction activity, safety methods should be implemented in accordance with OSHA (Occupational Safety and Health Act of 1979) guidelines. In accordance with OSHA guidelines, the following precautions and procedures should be employed for sludge land application projects:

- A safety manual should be available for use by employees and they should be trained in all safety procedures.
- Appropriate personal safety devices such as hardhats, gloves, safety glasses, and footwear should be provided to employees.
- Appropriate safety devices, such as rollbars, seatbelts, audible reverse warning devices, and fire extinguishers, should be provided on equipment used to transport, spread, or incorporate sludge.
- Fire extinguishers should be provided for equipment and buildings.

- Communications equipment should be available on site for emergency situations.

- Work areas and access roads should be well marked to avoid onsite vehicle mishaps.

- Adequate traffic control should be provided to promote an orderly traffic pattern to and from the land application site to maintain efficient operating conditions and avoid traffic jams on local highways.

- Public access to the sludge application site(s) should be controlled. The extent of the control necessary will depend on the sludge application option being used, time interval since sludge was last applied, and other factors. See the appropriate discussion in the applicable process design chapters (6 through 9) for the sludge application option being considered. In general, public access to dedicated disposal sites should be controlled at all times, while public access to application sites using other land application options should be controlled during sludge application operations and for an appropriate time period after the sludge is applied.

11.4 Health Concerns

11.4.1 General

A detailed discussion of pathogens and vectors which may be associated with sewage sludge is contained in Appendix A. Although bacteria, viruses, and parasites are generally present in sludge, studies conducted through 1982 by the EPA, and others, have shown no significant health problems for personnel who experience regular contact with sewage sludge at POTW's and/or sludge to land application sites (25)(28). Furthermore, epidemiological studies have shown no significant health problems to humans associated with living or working in proximity to sites receiving land application of sludge or wastewater (26)(27). This health effects research is continuing in attempting to fully document any potential health risks involved in direct or incidental contact with sewage sludge.

11.4.2 Personnel Health Safeguards

Project management should include health safeguards for personnel involved with sludge transport and handling, as follows:

- Receive regular typhoid and tetanus inoculations and poliovirus and adenovirus vaccinations.

- Limit direct contact with aerosols as much as possible where liquid sludge application techniques are used.

- Encourage proper personal hygiene.
- Provide annual employee health checkups.
- Record reported employee illnesses, and if a pattern (trend) develops of illnesses potentially associated with sludge pathogens, investigate and take appropriate action.

11.5 Monitoring

11.5.1 General

Sampling and analysis methods for sludge, surface water, ground water, soil, and crops are covered in Appendix C. This section will discuss the need for monitoring and frequency of sampling.

11.5.2 Sludge Monitoring

As discussed in Appendix A, there may be a wide variation in sludge physical and chemical characteristics between different POTW's, and, in addition, there are seasonal variations in the characteristics of sludge generated by a particular POTW. Therefore, analysis of the sludge on a regular basis is necessary to know exactly what is being applied to the land and to ensure acceptability of the sludge for land application, regardless of the land application option that is being used. The analytical data generated provide a quality control tool, a record of sludge variability, and a warning of the presence of high concentrations of undesirable constituents. In addition, data on plant nutrients (N, P, and K) are necessary to allow sludge users (e.g., farmers, commercial tree growers, etc.) to make efficient use of nutrients and to calculate sludge application rates.

The frequency of sludge sampling and analysis necessary will be a function of the following:

- System size; in general, the larger the system in terms of sludge generated, the more frequently the sludge will be sampled and analyzed. A very large system (e.g., serving a population of over 200,000) may sample daily, while a small system (e.g., under 5,000 population) may only sample sludge quarterly.
- Historical variations in sludge characteristics; in general, the greater the variability which has been found in sludge physical and/or chemical characteristics, the more often the sludge should be analyzed. Factors to be considered include contributions of wastewater from seasonal industries, POTW operational reliability, the dampening effect of large volume sludge storage, and the "normal" quality of the sludge, i.e., how seriously will fluctuations in the sludge characteristics affect the land application option feasibility?

- The land application option being utilized influences the necessary frequency of sludge sampling. In general, options which require accurate knowledge of sludge characteristics, e.g., agricultural utilization, may require more frequent sludge sampling than would an option not involving crop growth, e.g., dedicated land disposal without crops.

- An overriding factor usually is the sludge sampling frequency required by the cognizant regulatory agency.

The sludge parameters analyzed will also vary depending on the factors listed above, e.g., system size, historical sludge variability, type of land application option used, and regulatory agency requirements. Generally, as a minimum, sludge will be analyzed for pH, percent solids, N, P, K, and the heavy metals. In addition, if the system used is potentially sensitive to pathogens and/or priority organics these parameters may also be measured.

11.5.3 Soil Monitoring

The need for soil monitoring depends on the site characteristics and the sludge application option being utilized. Each of the design chapters discusses soil monitoring needs for the specific option being covered. In general, routine annual soil tests will provide the data required for monitoring purposes.

11.5.4 Vegetation Monitoring

Periodic analysis of the harvested portions of crops grown on the sludge-treated soil will aid in preventing accumulation of potentially phytotoxic materials. Vegetation monitoring will also signal the approach of increased levels well in advance of permanent damage to either soil or crop (15). Plants can also serve as effective indicators of excessive or insufficient levels for many soil constituents.

The need for, and frequency of, vegetation monitoring will vary depending on system specific factors. Generally, if sludge is applied at low, agronomic rates there is little need to sample and analyze the vegetation. If, however, sludge is being applied at high rates (e.g., dedicated land disposal with crop growth), the crop should be tested prior to harvesting for human or animal consumption. Tables in Appendix C provide suggested crop monitoring parameters and sampling procedures.

11.5.5 Ground Water Monitoring

Appendix C includes a discussion of ground water monitoring procedures. If ground water monitoring is needed, a hydrogeologist should be consulted during the initiation and implementation of a ground water monitoring program. Detailed ground water monitoring procedures can also be found in Reference (24).

Systems which apply sludge at low rates for agriculture generally do not monitor ground water quality. Conversely, dedicated land disposal sites are usually required to monitor ground water quality by the cognizant regulatory agency. If the forest land or land reclamation option is being utilized, ground water monitoring will probably be required for these application sites which could affect sensitive aquifers, e.g., the decision is made on a case-by-case basis by the operating agency and/or regulatory agency.

11.5.6 Surface Water Monitoring

Appendix C includes a section on surface water monitoring procedures.

11.6 Recordkeeping

Operational and monitoring data may be required by local, state, and/or federal regulatory agencies. Consequently, any municipality implementing a sludge application system, should develop an adequate recordkeeping program.

Management and reporting activities may include equipment use and maintenance records, performance records, required regulatory reports, cost records, and public relations activities (e.g., complaints). These records can also be used as the basis for scheduling site development and gauging the efficiency of operations.

Records on the sludge application portions of the program should contain at least the following:

- Sludge characteristics and amounts applied to specific locations.
- Major operational problems, complaints, or difficulties.
- Qualitative and/or quantitative data related to the operation of the land application site, including ground and surface water, soils, and crops.

Figure 11-1 depicts the sampling and analytical data form used by Defiance, Ohio. They utilize a map for the application area (Figure 11-2). The coding of each field allows the equipment operator to record the location and quantity of sludge applied on a daily basis. Figure 11-3 depicts the daily log sheet identifying sludge distribution information with specific land areas used in conjunction with this program.

Agricultural utilization projects must also be concerned about cumulative metal loadings. This type of data should be maintained on a regularly scheduled basis to provide an early warning when cumulative metal loadings begin to approach the recommended maximum levels.

SOURCE	SAMPLING FREQUENCY OEPA	NITROGEN					METALS												SOLIDS						OTHER												APPROX COST/ SAMPLE
		Tot. Kjeldahl	Tot. Organic	Tot. Ammonia	Tot. Nitrite	Tot. Nitrate	Tot. Aluminum	Tot. Cadmium	Tot. Chromium	Tot. Copper	Tot. Iron	Tot. Lead	Tot.Manganese	Tot.Magnesium	Tot. Mercury	Tot. Nickel	Tot.Potassium	Tot. Zinc	% Solids	% Volatile	Susp. Solids	Dissolved Sol		Total PCB	Tot. Coliform	Fecal " "	pH	TOC	COD	Phenol	Phosphorus	Oil & Grease	Density	Chlorides			
Digested Sludge	2/yr																																				
Surface Run-off	¼ yr																																				
Nagel Well Water	¼ yr																																				
Tile Filtrate	¼ yr																																				
Soil Samples	2/yr*																																				
Soil Samples (OSU Agonomic)	1/yr																																				
Corn Stalk	1/crop																																				
Corn Leaves	1/crop																																				
Corn Leaves (OSU - Nutrient)	1/crop																																				
Corn Grain	1/crop																																				

* Soil samples recommendation - Before and after crop

¼ yr = Every 3 months or quarterly
½ yr - Every 6 months or semi-annually

Figure 11-1. City of Defiance Water Pollution Control Department land application program: Sampling and analytical schedule.

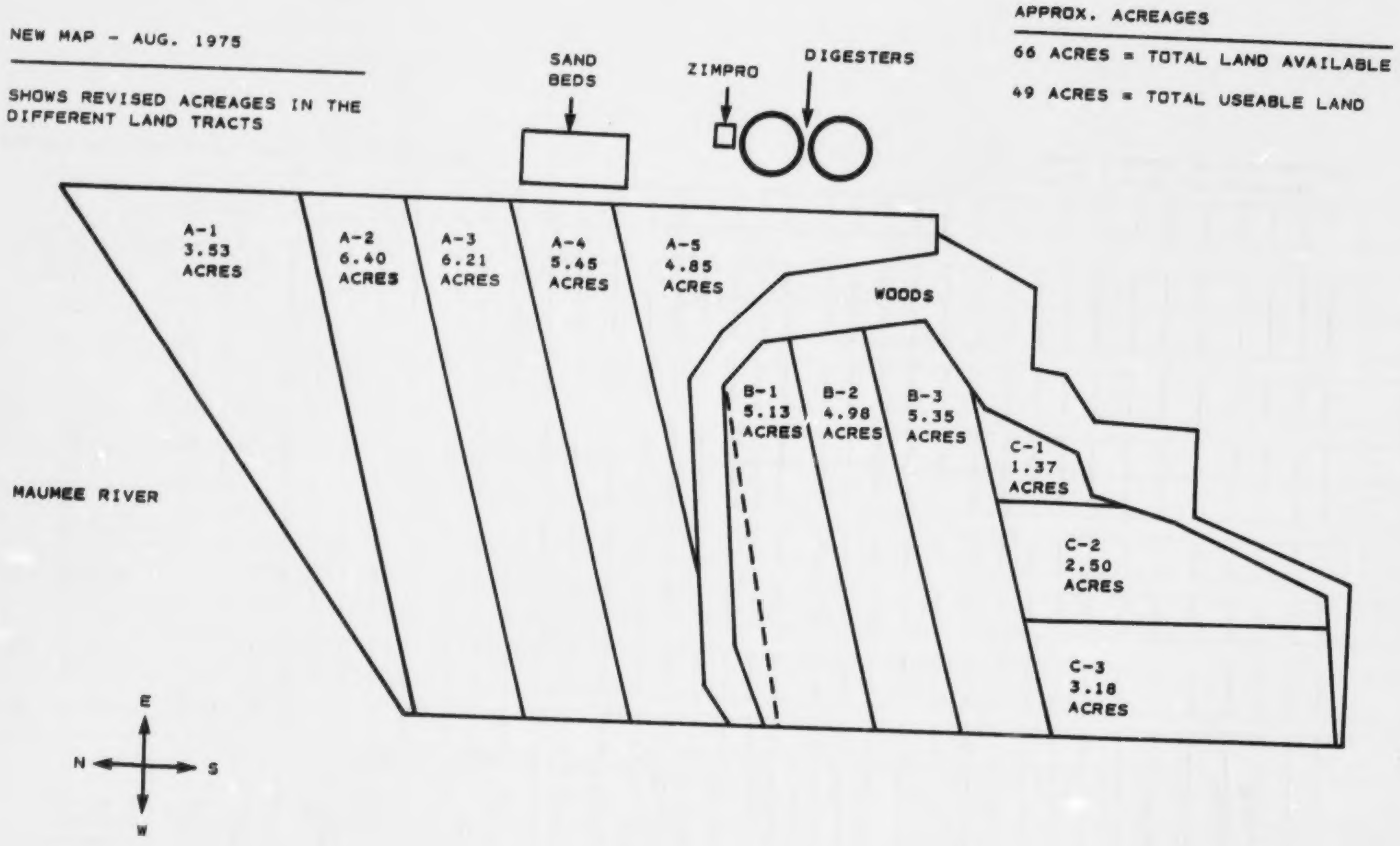

Figure 11-2. City of Defiance Water Pollution Control Department Land Application Project.

DAILY LOG SHEET

DATE ____________ OPERATOR ____________

SHIFT____________ TO ____________

LAND AREA	EQUIP USED	TYPE SLUDGE	NO. LOADS	TOTAL GAL. PER SHIFT/AREA
A1				
A2				
A3				
A4				
A5				
B1				
B2				
B3				
B1A				
C1				
C2				
C3				
PLANT LAND				
OTHER				

CODE

C = CONVERTAINER (2000 GALLON CAPACITY)
B = BADGER TANK (2700 GALLON CAPACITY)
G = GYMMY TANKER (2000 GALLON CAPACITY)
Z = ZIMPRO PROCESSED SLUDGE
D = DIGESTED SLUDGE
O = OTHER (SEE COMMENTS)

COMMENTS ____________

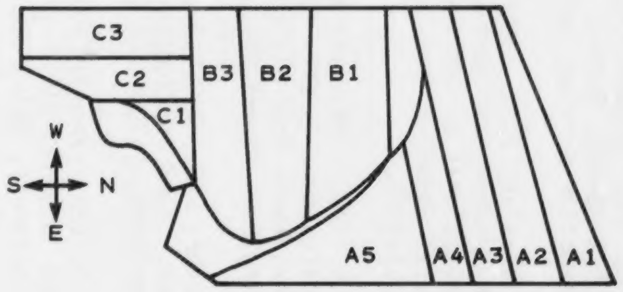

Figure 11-3. Daily log sheet, Defiance, Ohio.

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APPENDIX A

CHARACTERISTICS OF SEWAGE SLUDGE

A.1 Introduction

Reliable information on sludge composition is needed when designing land application systems in order to minimize the potential for environmental or health problems.

A wide range in concentrations for many sludge constituents is found in the tables of data presented in this Appendix. A variety of factors influence the composition of sludges, including the proportion of industrial and residential input, the amount of urban runoff, and the combination of treatment processes used. Thus, sludge composition is variable from one city to another, and even over time at a specific treatment plant.

The variability of sludge composition emphasizes the need for a sound sampling and analysis program. The use of flow weighted sampling procedures is strongly encouraged to obtain representative samples of the sludge(s) produced. The reliability of sludge composition data is improved by obtaining samples of sludge over a 1 to 2 year period, if possible. In addition, after a land application program has been initiated, an ongoing sludge sampling and analysis program is needed to verify that appropriate application rates are used so that these rates can be adjusted if any significant changes in sludge composition are encountered.

A.2 Characteristics of Raw Sludges

Table A-1 presents typical ranges of raw sludge characteristics generated by common wastewater treatment processes. The sludge volumes shown in Table A-1 should be viewed as general estimates and, at best, could be used in preliminary planning. Furthermore, sludges are virtually always treated by a stabilization process prior to land application. Stabilization processes include aerobic and anaerobic digestion, composting, drying, storage in a lagoon, etc. Stabilization processes will reduce the volume of raw sludge by 25 to 40 percent because much of the volatile solids are degraded to carbon dioxide, methane, and other end products. The actual amounts of stabilized sludge produced in a given treatment plant are dependent on operational parameters (temperature, mixing, detention time) and the process used.

TABLE A-1
QUANTITIES OF RAW SLUDGES PRODUCED BY VARIOUS TREATMENT PROCESSES (2)

Treatment Processes	kg Dry Solids/ 10^3m^3*	$m^3/10^6m^3$ Sewage Treated†	Percent Water in Sludge
Primary settling	108-144	2,500-3,500	93-95
Activated sludge	72-108	15,000-20,000	98-99
Trickling filters (low loading)	48-60	400-700	93-95
Trickling filters (high loading)	72-108	1,200-1,500	96-98
Chemical precipitation (raw sewage)	360-540	4,000-6,000	90-93

* 1 $kg/10^3m^3$ = 8.33 $lb/10^6$ gallons.

† 1 $m^3/10^6m^3$ = 1 $gal/10^6$ gal.

A.3 Sludge Composition Data

Several studies have been conducted to compile data on the chemical composition of municipal sludges produced by POTW's in various states (7) (12)(29)(33). The data presented in Tables A-2 through A-5 summarize the composition of sludges from within eight states, primarily in the midwest. Composition data are tabulated for sludges subjected to aerobic digestion, anaerobic digestion and other processes (i.e., lagoon, primary, trickling filter, etc.). The relationship between volume of wastewater treated and sludge composition has been evaluated for selected communities in Indiana (Table A-6). Similar data are presented in Table A-7 for sludge produced by selected communities in Iowa, but population ranges rather than volumes of wastewater treated are given. The composition of sludges from 16 large cities in the United States is shown in Table A-8.

The composition of sludge components does not follow a normal distribution because of variability in the specific nature of industrial and other nondomestic inputs into the sewage treatment plant. Several studies have shown that a log-normal distribution adequately describes sludge composition data. As a result, the median or gometric mean are better measures of "typical" concentration than the arithmetic mean. Wherever possible, median values have been incorporated into Table A-2 through A-7. The following sections will elaborate on the composition data.

A.3.1 Organic Carbon in Sludge

The organic C content of sludges can range from 6.5 to 48 percent (Table A-2). The median concentrations of organic C are relatively constant in most sewage sludges, ranging from 26.8 to 32.5 percent. A variety of

TABLE A-2
CONCENTRATIONS OF ORGANIC C, TOTAL N, P, AND S NH_4^+ AND NO_3^- IN SEWAGE SLUDGE (29)*

Component	Sludge Type†	Number	Range	Median	Mean
Organic C, %	Anaerobic	31	18-39	26.8	27.6
	Aerobic	10	27-37	29.5	31.7
	Other	60	6.5-48	32.5	32.6
	All	101	6.5-48	30.4	31.0
Total N, %	Anaerobic	85	0.5-17.6	4.2	5.0
	Aerobic	38	0.5-7.6	4.8	4.9
	Other	68	<0.1-10.0	1.8	1.9
	All	191	<0.1-17.6	3.3	3.9
NH_4^+-N, mg/kg	Anaerobic	67	120-67,600	1,600	9,400
	Aerobic	33	30-11,300	400	950
	Other	3	5-12,500	80	4,200
	All	103	5-67,600	920	6,540
NO_3^--N, mg/kg	Anaerobic	35	2-4,900	79	520
	Aerobic	8	7-830	180	300
	Other	3	--	--	780
	All	45	2-4,900	140	490
Total P, %	Anaerobic	86	0.5-14.3	3.0	3.3
	Aerobic	38	1.1-5.5	2.7	2.9
	Other	65	<0.1-3.3	1.0	1.3
	All	189	<0.1-14.3	2.3	2.5
Total S, %	Anaerobic	19	0.8-1.9	1.1	1.2
	Aerobic	9	0.6-1.1	0.8	0.8
	Other	--	--	--	--
	All	28	0.6-1.5	1.1	1.1

* Concentrations and percent composition are on a dried solids basis.

† "Other" includes lagooned, primary, tertiary, and unspecified sludges. "All" signifies data for all types of sludges.

TABLE A-3
CONCENTRATIONS OF K, Na, Ca, Mg, Ba, Fe, AND Al IN SEWAGE SLUDGE (29)*

Component	Type†	Number	Range	Median	Mean
K, %	Anaerobic	86	0.02-2.64	0.30	0.52
	Aerobic	37	0.08-1.10	0.39	0.46
	Other	69	0.02-0.87	0.17	0.20
	All	192	0.02-2.64	0.30	0.40
Na, %	Anaerobic	73	0.01-2.19	0.73	0.70
	Aerobic	36	0.03-3.07	0.77	1.11
	Other	67	0.01-0.96	0.11	0.13
	All	176	0.01-3.07	0.24	0.57
Ca, %	Anaerobic	87	1.9-20.0	4.9	5.8
	Aerobic	37	0.6-13.5	3.0	3.3
	Other	69	0.12-25.0	3.4	4.6
	All	193	0.1-25.0	3.9	4.9
Mg, %	Anaerobic	87	0.03-1.92	0.48	0.58
	Aerobic	37	0.03-1.10	0.41	0.52
	Other	65	0.03-1.97	0.43	0.50
	All	189	0.03-1.97	0.45	0.54
Ba, %	Anaerobic	27	<0.01-0.90	0.05	0.08
	Aerobic	10	<0.01-0.03	0.02	0.02
	Other	23	<0.01-0.44	<0.01	0.04
	All	60	<0.01-0.90	0.02	0.06
Fe, %	Anaerobic	96	0.1-15.3	1.2	1.6
	Aerobic	38	0.1-4.0	1.0	1.1
	Other	31	<0.1-4.2	0.1	0.8
	All	165	<0.1-15.3	1.1	1.3
Al, %	Anaerobic	73	0.1-13.5	0.5	1.7
	Aerobic	37	0.1-2.3	0.4	0.7
	Other	23	0.1-2.6	0.1	0.3
	All	133	0.1-13.5	0.4	1.2

* Concentrations on a dry solids basis.

† "Other" includes lagooned, primary, tertiary, and unspecified sludges. "All" signifies data for all types of sludges.

TABLE A-4
CONCENTRATIONS OF Pb, Zn, Cu, Ni, Cd, AND Cr IN SEWAGE SLUDGE (29)[*]

Component	Type[†]	Number	Range	Median	Mean
			- - - - - (mg/kg)- - - - -		
Pb, mg/kg	Anaerobic	98	58-19,730	540	1,640
	Aerobic	57	13-15,000	300	720
	Other	34	72-12,400	620	1,630
	All	189	13-19,700	500	1,360
Zn, mg/kg	Anaerobic	108	108-27,800	1,890	3,380
	Aerobic	58	108-14,900	1,800	2,170
	Other	42	101-15,100	1,100	2,140
	All	208	101-27,800	1,740	2,790
Cu, mg/kg	Anaerobic	108	85-10,100	1,000	1,420
	Aerobic	58	85-2,900	970	940
	Other	39	84-10,400	390	1,020
	All	205	84-10,400	850	1,210
Ni, mg/kg	Anaerobic	85	2-3,520	85	400
	Aerobic	46	2-1,700	31	150
	Other	34	15-2,800	118	360
	All	165	2-3,520	82	320
Cd, mg/kg	Anaerobic	98	3-3,410	16	106
	Aerobic	57	5-2,170	16	135
	Other	34	4-520	14	70
	All	189	3-3,410	16	110
Cr, mg/kg	Anaerobic	94	24-28,850	1,350	2,070
	Aerobic	53	10-13,600	260	1,270
	Other	33	22-99,000	640	6,390
	All	180	10-99,000	890	2,620

[*] Concentrations are on a dried solid basis.

[†] "Other" includes lagooned, primary, tertiary, and unspecified sludges. "All" signifies data for all types of sludges.

TABLE A-5
CONCENTRATIONS OF Mn, B, As, Co, Mo, AND Hg IN SEWAGE SLUDGE (29)*

Component	Type[†]	Number	Range	Median	Mean
				-(mg/kg)-	
Mn, mg/kg	Anaerobic	81	58-7,100	280	400
	Aerobic	38	55-1,120	340	420
	Other	24	18-1,840	118	250
	All	143	18-7,100	260	380
B, mg/kg	Anaerobic	62	12-760	36	97
	Aerobic	29	17-74	33	40
	Other	18	4-700	16	69
	All	109	4-760	33	77
As, mg/kg	Anaerobic	3	10-230	116	119
	Aerobic	--	--	--	--
	Other	7	6-18	9	11
	All	10	6-230	10	43
Co, mg/kg	Anaerobic	4	3-18	7.0	8.8
	Aerobic	--	--	--	--
	Other	9	1-11	4.0	4.3
	All	13	1-18	4.0	5.3
Mo, mg/kg	Anaerobic	9	24-30	30	29
	Aerobic	3	30-30	30	30
	Other	17	5-39	30	27
	All	29	5-39	30	28
Hg, mg/kg	Anaerobic	35	0.5-10,600	5	1,100
	Aerobic	20	1.0-22	5	7
	Other	23	2.0-5,300	3	810
	All	78	0.2-10,600	5	733

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* Concentrations on a dry solids basis.

* "Other" includes lagooned, primary, tertiary, and unspecified sludges. "All" signifies data for all types of sludges.

TABLE A-6
RELATIONSHIP BETWEEN QUANTITY OF WASTEWATER TREATED AND CHEMICAL COMPOSITION OF SLUDGES IN INDIANA (7)

Component	Flow Treated, $m^3/day \times 10^3$				
	4-10 (20)*	10-20 (12)	20-40 (9)	40-80 (10)	780 (7)
			%†		
Total N	8.94	6.00	7.05	6.81	5.36
NH_4-N	1.76	1.11	1.34	1.10	1.08
			mg/kg†		
Zn	1,155	1,655	1,800	2,410	1,980
Cd	9	22	18	36	62
Cu	610	1,320	640	790	510
Ni	84	180	80	280	-
Pb	350	480	380	450	-
Cr	440	690	590	1,140	885
PCB	8.1	4.5	6.7	6.7	14.5

* Number of treatment plants studies.

† Median concentrations on a dry solids basis.

English conversion factor:

$1\ m^3 = 264.2$ gal.

TABLE A-7
RELATIONSHIPS BETWEEN POPULATION IN SANITARY DISTRICT AND CHEMICAL COMPOSITION OF SEWAGE SLUDGES FROM DIFFERENT SIZE CITIES IN IOWA (33)*

	Population of City x 10^3*				
Component	<2	2-10	10-25	25-60	>60
	(%)†				
Organic C	39.2	28.4	35.4	28.0	28.5
Total N	2.55	3.19	2.81	1.52	2.28
NH_4^+-N	0.085	0.057	0.080	0.082	0.072
NO_3^--N	0.018	0.014	0.018	0.011	0.015
P	1.12	1.43	0.95	1.55	1.22
S	0.75	1.34	0.98	1.16	1.10
Ca	5.19	8.22	5.75	9.25	8.08
Mg	0.58	0.59	0.52	0.88	0.73
Na	0.18	0.54	0.17	0.09	0.21
K	0.24	0.28	0.21	0.19	0.31
Fe	1.72	1.94	1.79	1.66	2.13
	(mg/kg)†				
Ag	9	18	9	25	11
As	169	163	175	163	171
B	100	226	78	88	130
Cd	18	27	14	20	28
Co	18	25	21	18	24
Cr	38	250	369	150	213
Cu	294	407	225	225	200
Hg	1.2	2.9	0.8	1.5	0.4
Mn	194	557	232	288	363
Mo	13	13	13	13	13
Ni	25	38	25	38	38
Pb	183	175	213	325	300
Se	<25	<25	<25	<25	<25
V	25	25	28	26	38
Zn	1,000	1,750	575	1,175	1,625

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* Concentrations and percent composition are on a dry solids basis.

† Median concentration in sewage sludge from city with a population x 10^3.

TABLE A-8

CONCENTRATIONS OF SELECTED CONSTITUENTS IN SEWAGE SLUDGES (10)

City	Dieldrin	PCB's	As	B	Cd	Co	Cr	Cu	Hg	Mn	Mo	Ni	Pb	Se
	(mg/kg)*													
1	0.26	3.80	3.6	22	104	9	1,320	1,463	7	267	6	169	1,445	2
2	<0.03	0.79	3.0	30	7	4	169	821	11	128	1	36	136	2
3	0.24	11.60	29	44	15	4	207	578	6	95	11	51	605	2
4	0.16	1.60	14	30	46	9	936	1,370	4	224	18	562	1,011	4
5	0.28	0.35	20	36	112	6	3,480	1,560	4	102	10	102	2,236	-
6	0.06	4.30	4.8	40	67	10	640	1,300	14	527	21	166	329	5
7	0.44	4.00	26	90	171	17	4,925	2,890	7	116	40	402	3,065	9
8	0.43	8.50	10	33	150	18	1,430	1,200	16	32	37	453	1,467	3
9	0.05	2.20	3.3	30	444	4	14,000	1,288	3	134	33	360	1,253	2
10	-	-	8.0	50	30	6	646	1,890	15	152	5	140	1,976	3
11	2.2	4.80	16.2	44	192	16	2,320	2,680	5	95	8	432	7,627	3
12	0.06	<0.01	6.4	22	8	5	1,500	90	18	113	2	223	2,521	3
13	0.04	23.10	21.9	33	22	16	458	900	9	235	26	72	598	5
14	0.10	0.50	30.0	40	64	9	1,320	1,170	8	350	2	153	2,411	3
15	0.05	6.60	26.0	32	200	5	1,000	1,060	6	216	4	211	1,412	2
16	-	-	6.6	16	31	15	1,260	458	6	323	4	-	498	2

* Concentrations are on a dry solids basis.

organic components are present in sludges, including microbial cells and their decomposition products, chemical compounds present in the wastewater influent (proteins, polysaccharides, greases, and fats), and compounds synthesized during the wastewater and sludge treatment processes. The chemical composition of sludge organic C has not been completely defined. Recent studies indicate that phthalate esters, waxes, and fatty acids are contained in the nonaqueous solvent (e.g., hexane) extractable fraction of sludges (32). It was also shown that a variety of amino acids and two sugars (glucose and xylose) were released from the sludge solids by acid hydrolysis. Some priority pollutants (e.g., PCB's, chlorinated hydrocarbons) can also be present in the organic fraction of sludges, but their concentrations are typically well under 100 mg/kg.

Most of the organic C found in sludges is insoluble in water, and consists of various proteinaceous, polysaccharide, and lipid-type materials in various stages of decomposition. The insoluble nature of sludge organic C means that it is not appreciably removed by dewatering processes. The organic C content of sludges placed on sand-drying beds or composted, however, can be markedly reduced because of the additional microbial decomposition which occurs during these processes.

A.3.2 Nitrogen Compounds in Sludge

The concentrations of organic nitrogen, NH_4 and NO_3 in sludge are affected by the type of sludge treatment and handling processes used. Most of the organic N in sludges is associated with the sludge solids and thus organic N levels are not appreciably altered by sludge dewatering or drying procedures. In contrast, the inorganic forms of N (NH_4 and NO_3) are water soluble, and their concentrations will decrease dramatically during dewatering steps, e.g., drying-beds, centrifuges, presses, etc. Either heat or air drying will reduce the NH_4 because of ammonia volatilization, but not the NO_3 level.

Usually, over 90 percent of the inorganic N will be as NH_4, unless aerobic conditions have prevailed during sludge treatment. For most liquid sludges collected from an anaerobic digester, essentially all the inorganic N will be present as NH_4, and will constitute from 25 to 50 percent of the total N. The NH_4 concentration in the liquid phase of sludge is relatively constant at a specific treatment plant. Dewatering of liquid sludges will substantially lower the NH_4 content, resulting in a sludge with less than 10 percent of the total N being present as NH_4. Since the inorganic N content of sludges is significantly influenced by sludge handling procedures, it is essential that nitrogen analysis be conducted on the actual sludge being considered for land application.

The organic N content of sludges can range from 1 to 10 percent on a dry weight basis. The organic N compounds found in sludges are primarily amino acids, indicating the presence of proteinaceous materials (26) (30). It is likely that the proteins have been partially degraded, and can be incorporated into stable, humic-type materials. Small amounts of hexosamines and amides are also found in the organic N fraction of sludges. After application to soils, soil microbes will decompose the organic matter contained in the sludge, resulting in release of NH_4^+ which can be assimilated by the vegetation grown.

The amount of inorganic N mineralized in soils is affected by the extent of sludge processing (e.g., digestion, composting) within the sewage treatment plant. The amounts of N mineralized in soils will generally be less for well stabilized sludges. The amounts of N mineralized after sludge application to soils are discussed in Chapter 6.

A.3.3 Other Components in Sludge

Sewage sludges contain varying concentrations of the other macro- and micronutrients and other components required for plant growth, as shown in Tables A-2 through A-5, which include data on sludge levels for P, K, S, Ca, Mg, Na, Cu, Zn, B, Mo, Fe, Mn, and Co. Several generalizations are possible concerning the expected concentrations and behavior of these elements in sludge or sludge soil systems.

Many elements enter the sewage treatment plant as soluble ions, and do not readily form either sparingly soluble compounds or stable complexes with particulate materials. Elements in this group include K^+, Na^+, NH_4^+, Mo, and Co. As a result, the majority of these elements entering a treatment plant are discharged in the treated effluent, unless special advanced treatment processes are used to remove them. Since these ions are water-soluble, sludge dewatering by centrifuges or presses will dramatically lower their concentrations in sludge solids; air or heat drying will result in increased levels because those ions, which are non-volatile.

Another group of elements readily forms insoluble compounds with constituents which are either initially present in the sewage or produced during sludge treatment. Included are both inorganic anions (P, S, and As) and cations (Ca, Mg, Fe, Al, Mn, Zn, Cu, Ni, Pb, Cd, Cr, and Hg). A variety of inorganic precipitates can form, including hydroxides, oxides, carbonates, phosphates, and sulfides; pH, redox potential, and solution composition will determine which precipitates are formed. The black color associated with anaerobically digested sludges is attributed to the formation of insoluble FeS.

Many trace metals, such as Cd, coprecipitate to form insoluble compounds in sludges. For example, Cd may be trapped within $Al(OH)_3$ or $CaCO_3$ solids phases during the precipitation process. In addition, metals (Cu, Zn, Cd, etc.) and anions ($H_2PO_4^-$, $H_2AsO_4^-$) can be adsorbed on the surface of organic matter or precipitates ($CaCO_3$, $Al(OH)_3$) in sludges. Because these chemical reactions remove the ion from solution and concentrate it in the solid phase, sludge dewatering has a minimal impact on their concentration in the final sludge.

A.3.4 Trace Organics in Sludge

A variety of organic compounds, primarily of industrial origin, have been receiving greater emphasis as potential pollutants of soils, crops, and waters following land application of sludges. Initially, chlorinated hydrocarbons, pesticides, and polychlorinated biphenyls were the major organics studied. Data collected in the mid-70's on the concentrations of dieldrin (a pesticide) and PCB's were shown in Table A-8 for selected large cities in the United States. Dieldrin concentrations were generally less than 0.3 mg/kg while PCB's ranged from under 0.01 to 23 mg/kg. A survey of sludges produced by treatment plants in Indiana indicated that the median PCB concentrations ranged from 4.5 to 14.5 mg/kg (Table A-6). The levels of PCB's in sludges should decrease in the future because these compounds are no longer being manufactured.

More recent research has concentrated on characterizing the myriad of trace organic compounds that are entering municipal sewage treatment plants (4). Analysis of sludges from 25 cities has indicated that several phthalate esters (i.e., diethyl, dibutyl) are present in 13 to 25 percent of sludges at concentrations above 50 mg/kg (Table A-9). Toluene, phenol, and naphthalene were also found in 11 to 25 percent of the sludges at higher than 50 mg/kg levels. Chlorinated methanes, ethanes, and benzenes were found in 3 to 36 percent of the sludges at concentrations above 1 mg/kg, but they were found in relatively few sludges at above 50 mg/kg. Trace organics have also been surveyed in 238 sludges generated by treatment plants in Michigan (Table A-10). The compounds detected in these sludges included acrylonitrile, chlorinated hydrocarbons, chlorinated benzenes, chlorinated phenols, styrene, and hydroquinone. Compounds found in over 25 percent of the sludges include 1,2- and 1,3-dichloropropane, 1,3-dichloropropene, tetrachloroethylene, 2,4,-dinitrophenol, hydroquinone, pentachlorophenol, phenol, and 2,4,6,-trichlorophenol. Of these compounds, median concentrations were below 5 mg/kg, except for tetrachloroethylene (29 mg/kg). Styrene was found in 6 of 219 sludges, ranging in concentration from 99 to 5,858 mg/kg. Chlorobenzene and chlorotoluene were present in 6 sludges at levels ranging from 60 to 846 mg/kg. These data suggest that most trace organics will be present in most sludges at concentrations of less than 10 mg/kg. However, industrial in-put of a specific organic compounds can dramatically increase sludge concentrations. Both of these studies have shown that there is a weak relationship between the proportion of total flow contributed by industries and the concentration of trace organics in sludges (4)(25).

A.4 Effect of Sludge Treatment and Chemical Amendments on Sludge Characteristics

The sludge treatment processes used can have a significant affect on the chemical composition of sludge. Sludge stabilization processes such as aerobic and anaerobic digestion result in decomposition of sludge organic matter and the release of carbon dioxide, ammonium, hydrogen sulfide, and phosphate. Thus, the organic C, N, S, and P content in

TABLE A-9
ORGANIC COMPOUNDS DETECTED IN SLUDGES (4)*

Compound	Percent Occurrence at Indicated Concentrations†		
	>1 mg/kg	>10 mg/kg	>50 mg/kg
Methane, dichloro-	41	12	3
Methane, trichloro-	3	0	0
Ethane, 1,1,1-trichloro-	5	3	0
Ethane, trichloro-	26	9	3
Ethane, tetrachloro-	27	8	3
Benzene, 1,4-dichloro	36	18	5
Ethylbenzene	33	3	0
Toluene	59	35	11
Phenol	63	25	13
Naphthalene	65	33	15
Phenanthrene	60	20	8
Phthalate diethyl	43	23	13
Phthalate, di-n-butyl	63	25	13
Phthalate, bis (2-ethyl hexyl)	75	63	25
Phthalate, butylbenzyl	50	35	18
All others	<50	<25	<15

* Survey of 25 cities located throughout the United States. Plant treated from 13,200 m^3/day to 1,170,000 m^3/day and percentage of industrial flow varied from 0 to 60 percent.

† Dry solids basis.

TABLE A-10
CHARACTERIZATION OF ORGANIC COMPOUNDS IN 238 SLUDGES COLLECTED FROM TREATMENT PLANTS IN MICHIGAN (25)

	- - - - - - - - - -	-mg/kg (dry weight)# - -	- - - - -	- - -
Compound	**Detection Limit***	**Range**	**Mean†**	**Median**
Acrylonitrile	4 (25/155)	4-82	16±19	7
Chlorobenzene	60 (3/158)	60-846	337±441	106
p-chlorotoluene	59 (6/158)	93-324	153±87	.121
o-dichlorobenzene	6 (15/215)	6-809	89±209	16
m-dichlorobenzene	5 (44/216)	6-1,651	119±327	22
p-dichlorobenzene	10 (18/216)	10-633	77±151	23
1,2-dichloropropane	0.08 (91/157)	0.09-66	1.91±7.36	0.66
1,3-dichloropropane	0.5 (40/158)	0.6-309	18±51	3.2
1,3-dichloropropane	0.1 (119/157)	0.1-1,232	24±116	3.9
Ethylbenzene	0.08 (14/220)	1.2-66	25±22	20
Hexachloro-1,3-butadiene	3 (1/217)	-	4	-
Hexachloroethane	0.05 (40/217)	0.05-16.5	0.7±2.6	0.2
Pentachloroethane	0.4 (5/199)	0.4-9.2	2.7±3.7	1.3
Styrene	90 (6/219)	99-5,848	1,338±2,249	405
Tetrachloroethylene	10 (108/128)	1-1,218	68±132	29
1,2,3-trichlorobenzene	1 (7/216)	1-152	25±56	1
1,2,4-trichlorobenzene	3 (17/217)	3-51	14±12	13
1,3,5-trichlorobenzene	50 (0/217)	-	-	-
1,2,3-trichloropropane	4 (2/141)	9-19	14±7	14
1,2,3-trichloropropane	3 (21/137)	3-167	23±47	6
o-chlorophenol	0.03 (20/231)		13±23	
m-chlorophenol	0.03 (16/231)	0.1-93	9±24	0.9
p-chlorophenol	0.03 (19/231)	0.1-90	18±30	3.6
o-cresol	0.03 (16/231)	0.2-183	25±52	2.0
2,4-dichlorophenol	0.03 (17/230)	0.2-203	25±54	4.8
2,4-dimethylphenol	0.03 (41/231)	0.09-87	6.5±14.9	2.2
4,6-dinitro-o-cresol	0.06 (20/229)	0.2-187	12.7±41	2.3
2,4-dinitrophenol	0.18 (66/228)	0.3-500	24±81	5.0
Hydroquinone	0.07 (61/229)	0.1-223	8±29	2.6
Pentachlorophenol	0.03 (155/223)	0.2-8,495	81±685	5.0
Phenol	0.03 (178/229)	0.05-288	9±29	2.0
2,4,6-trichlorophenol	0.06 (66/223)	0.2-1,333	42±178	4.8

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* Number in parenthesis is the number of sites having concentrations less than detection limit/total number of sites analyzed.

† Mean ± standard deviations.

# Concentrations on a dry solids basis.

stabilized sludges will be lower than the raw sludge entering the stabilization unit. Composting of sludges results in further decreases in the organic constituents found in sludges. In addition, composting may involve mixing sludge with a bulking agent (e.g., wood chips) to facilitate aeration and rapid stabilization of the sludge. In some cases, the majority of the bulking agent is removed from the finished compost by screening; but even in these cases a portion of the bulking agent remains in the compost resulting in dilution of sludge components (e.g., nutrients, metals). The extensive biological activity occurring during composting results in further decreases in the organic N, C, and S content of the sludge. In general, the organic N content of sludges decreases in the following order: raw, primary or wasted activated, digested, and composted.

Wastewater and sludge treatment processes often involve the addition of ferric chloride, alum, lime, or polymers. Obviously, the concentration of the elements added will increase their concentration in the resultant sludge. In addition, the compound added can have other indirect effects on sludge composition. For example, alum precipitates as aluminum hydroxides, which can subsequently adsorb P and coprecipatate with trace metals such as Cd. Lime (calcium oxide or hydroxide) used as a sludge stabilization agent will ultimately precipitate in sludges as calcium carbonate which can also retain P and metals. Lime addition may also result in alkaline hydrolysis of organic N compounds and cause losses of ammonia through volatilization.

A.5 Variability of Sludge Composition

The data discussed previously have emphasized the variability that can be encountered in the composition of sludges generated in different municipalities. The composition of sludges can also vary with time at a given treatment plant. Several studies have been conducted to assess the variable nature of sludge characteristics (6)(15)(31). Representative data on the variability of total N, P, and K (Figure A-1) and Zn, Cd, and Cu (Figure A-2) in sludges are shown for samples obtained from two treatment plants in Pennsylvania during a two year period. It is apparent that significant variations in sludge composition can occur both for constituents that are primarily soluble (K) or insoluble (P and metals), but this may differ between POTW's. The volume and frequency of industrial metal in-puts are probably responsible for the variations found in the Zn, Cd, and Cu concentrations. Also, operational parameters within the treatment plant can alter the solids content and other sludge characteristics. Not all cities generate sludges as variable as those depicted in Figures A-1 and A-2.

The data shown on the variability of sludge composition emphasize the need for a sound sampling program. The use of flow-weighted sampling procedures is strongly encouraged to obtain representative samples of sludge produced at a specific treatment plant. An on-going sludge sampling and analysis program is essential to assure the integrity of a land application system. Only through proper monitoring can significant

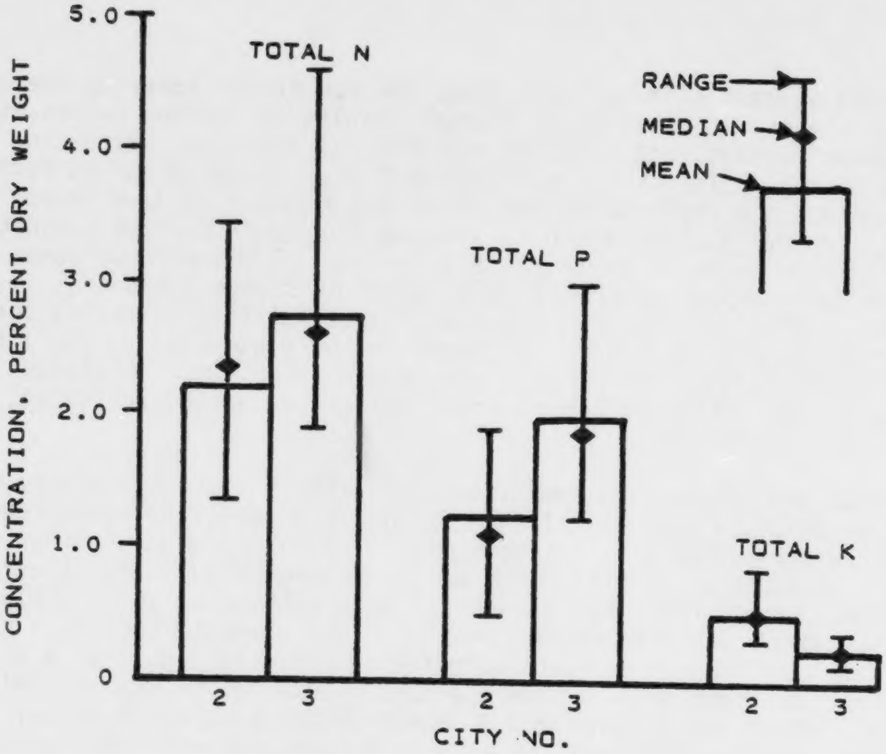

Figure A-1. Variability of N, P, and K in sewage sludge (6).

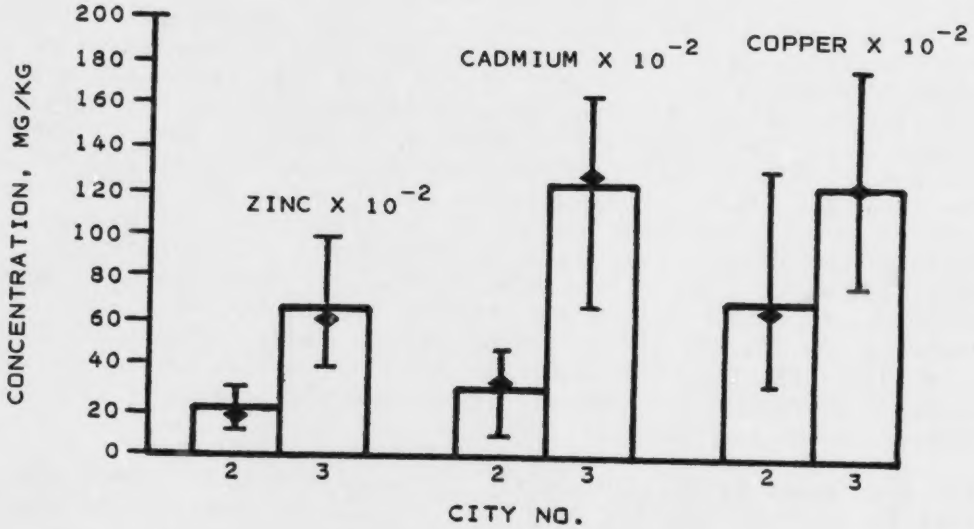

Figure A-2. Variability of Zn, Cd, and Cu in sewage sludge from two POTW's in Pennsylvania over a 2-year period (6).

changes in the concentration of limiting nutrients or metals be detected, so that sludge application rates can be altered accordingly.

A.6 Pathogens Potentially Associated with Sludge

A.6.1 General

Pathogenic microorganisms such as bacteria, viruses, protozoa, and parasitic worms are almost always present in raw sewage. The number and types of organisms present in raw sewage, however, varies from community to community, depending upon urbanization, population density, sanitary habits, season of the year, rates of disease in the contributing community (13). Table A-11 lists disease-causing bacteria and parasites which have been identified in raw sewage and sludge, and Table A-12 lists human enteric viruses which have been isolated from sewage (11). Sludge stabilization processes destroy the great majority of the pathogens listed in Tables A-1 and A-2, as discussed in Section A6.6.

A.6.2 Bacteria

Enteric bacilli, which naturally inhabit the gastrointestinal tract of man, have been classified into three general categories: pseudomonas, salmonella, and shigella species. *None of the enteric bacilli form spores*. Spores are resistant bodies produced within the cells of a large number of bacterial species which enables them to withstand unfavorable environmental conditions such as heat, cold, desiccation, and chemicals (12). Since enteric bacilli are non-spore formers, their survival outside their normal environment is usually measured in days or months, compared to years for spore-forming bacteria. The most common bacterial pathogens associated with sewage are *Salmonella*, *Shigella*, *Vibrio*, and *Campylobacter* (Table A-11). More than 110 different virus types may be present in raw sewage (Table A-12). The list of pathogenic human enteric viruses has continued to grow during the last decade. Rotaviruses are now recognized as a major cause of child gastroenteritis, and also cause diarrhea in adults (11). Other major pathogenic enteric viruses are the *Polioviruses*, *Coxsackieviruses*, *Echoviruses*, and the *Hepatitis virus*. These viruses are shed from the body through the feces, and fecal-oral spread is probably the most common method of transmission. For man, the enteric virus of greatest potential concern appears to be Hepatitis A.

A.6.3 Parasites

Parasites include protozoans, nematodes, and helminths (Table A-11). Intestinal protozoans are transmitted by a cyst, the nonactive and environmentally insensitive form of the organism. Their life cycle requires that a cyst be ingested by the host. The cyst is transformed into an active feeding organism (trophozoite) in the intestines, where it matures and reproduces, releasing cysts in the feces (25).

TABLE A-11
BACTERIA AND PARASITES IN SEWAGE AND SLUDGE

Group	Pathogen	Disease Caused
Bacteria	Salmonella (1700 types)	Typhoid, paratyphoid, salmonellosis
	Shigella	Bacillary dysentery
	Enteropathogenic *Escherichia coli*	Gastroenteritis
	Yersinia enterocolitica	Gastroenteritis
	Campylobacter jejuni	Gastroenteritis
	Vibrio cholerae	Cholera
	Leptospira	Weil's disease
Protozoa	*Entamoeba histolytica*	Amebic dysentery, liver abcess, colonid ulceration
	Giardia lamblia	Diarrhea, malabsorption
	Balantidium coli	Mild diarrhea, colonic ulceration
Helminths	*Ascaris lumbricoides* (Roundworm)	Ascariasis
	Ancyclostoma duodenale (Hookworm)	Anemia
	Necator americanus (Hookworm)	Anemia
	Taenia saginata (Tapeworm)	Taeniasis

TABLE A-12
HUMAN ENTERIC VIRUSES IN SEWAGE

Virus	Number of Types	Diseases Caused
Enteroviruses:		
Poliovirus	3	Meningitis, paralysis, fever
Echovirus	31	Meningitis, diarrhea, rash, fever, respiratory disease
Coxsackievirus	23	Meningitis, herpangina, fever, respiratory disease
Coxsackievirus	6	Myocraditis, congential heart anomalies, pleurodynia, respiratory disease, fever, rash, meningitis
New enteroviruses (Types 68-71)	4	Meningitis, encephalitis, acute hemorrhagic conjunctivitis, fever, respiratory disease
Hepatitis Type A (enterovirus 72?)	4	Infectious hepatitis
Norwalk virus	1	Diarrhea, vomiting, fever
Calicivirus	1	Gastroenteritis
Astrovirus	1	Gastroenteritis
Reovirus	3	Not clearly established
Rotavirus	2	Diarrhea, vomiting
Adenovirus	37	Respiratory disease, eye infections

Of the common protozoa which may be found in sewage, only three species are of major significance for transmission of disease to human: Entamoeba histolytica, Giarda lambia, and Balantidium coli. All of these organisms are known to cause mild to severe diarrhea (11).

Although helminth infections are still prevalent in the U.S. population, the occurrence of disease due to three agents in the United States has been extremely low during the last few decades. The presence and levels in wastewater of helminth eggs depend on the levels of disease in the population (11). Helminths (worms) include the subgroups, nematodes and trematodes. The intestinal nematode, Ascaris lumbricoides, is frequently mentioned as a potential problem to human health. Parasitic ova are generally quite resistant to disinfectants and adverse environmental conditions (12). The ova of Ascaris have been shown to survive sewage treatment. Since a portion of animal waste reaches municipal sludges, parasites of animal origin are also of concern. The nemathodes, Toxacara canis and T. cati, found in the dog and cat population, have a life cycle which is nearly identical to that of Ascaris in man (28).

A.6.4 Fungi

Fungi are secondary pathogens in sludge. A large number have been found growing in sludge undergoing composting. The pathogenic fungi are of most concern when the spores are inhaled by people who are already stressed by a disease such as diabetes or by immunosuppressive drugs (20).

Fungi spores, especially those of Aspergillus fumigatus, are ubiquitous in the environment, and have been found in pastures, haystacks, manure piles, and the basements of most homes. This fungus grows exceptionally well at human body temperature, and causes asthmatic symptoms in allergy-prone individuals.

Although there is a greater potential of transacting pathogenic fungi and actinomycetes during composting, there is also a possibility of inhaling such spores while applying sludge to land. However, there have been no reports involving such cases at sludge-to-land sites (3).

A7.0 Reduction of Pathogens by Sewage and Sludge Treatment Processes

Sewage and sludge treatment processes significantly reduce the number of pathogens originally present in the raw sewage. Table A-13 shows percent removal of pathogens by various sewage treatment processes. It is clear, however, that some pathogens may survive sludge stabilization processes. Table A-14 lists reported concentrations of enteric viruses in sludge receiving various types of treatment. As shown in the table, sludge which has been stabilized (e.g., digested, lagooned) has very low concentrations of viruses compared to raw sludge.

Table A-15 shows reported parasite concentration in raw and treated sludge. As shown in the table, parasite eggs have high survival rates

TABLE A-13
PERCENT REMOVAL OF PATHOGENS BY VARIOUS SEWAGE TREATMENT PROCESSES (9)

Treatment	Enteric Viruses	Bacteria	Protozoan Cysts	Helminth Eggs
Primary Sedimentation	0-30	50-90	10-50	30-90
Trickling Filter*	90-95	90-95	50-90	50-95
Activated Sludge*	90-99	90-99	50	50-99
Oxidation Ditch*	90-99	90-99	50	50-99
Waste Stabilization Ponds (three cells with ≥25 days' retention)	99.99-100	99.99-100	100	100

* With sedimentation, sludge digestion, and sludge drying.

TABLE A-14
REPORTED CONCENTRATION OF ENTERIC VIRUSES IN SLUDGES (11)

Type of Sludge	Concentration	Location
Raw	5-145 pfu/ml	Cincinnati
Mixed liquor suspended solids	5 $TCID_{50}$/g	Florida
Aerobically digested	1.7 to 5.2 $TCID_{50}$	
Lagooned sludge applied to land	0.02 to 4.6	
Raw	6.9 to 215 pfu/g	
Digested	0.2 to 17 pfu/g	
Lagooned	1.2 pfu/g	
Raw	17.9 $TCID_{50}$/100 ml	
Anaerobic-mesophilic	0.85 $TCID_{50}$/100 ml	
Raw	40 to 1,419 pfu/g	England
Anaerobic-mesophilic digestion	6 to 210 pfu/g	
Aerobic-thermophilic digestion	10 to 65 pfu/g	
Anaerobic high rate digestion	1.1 to 17 pfu/g	United States
Anaerobically digested lagoon	1.2 pfu/g	
Anaerobic digestion	5.0-6.7 pfu/g	
Raw	141-1,060 pfu/100 ml	
Anaerobic-mesophilic	4-100 pfu/100 ml	
Aerobic-thermophilic	0-14 pfu/100 ml	
Anaerobic-mesophilic	0.8 pfu/ml	
Aerobic digestion	14 to 260 $TCID_{50}$/g	

TABLE A-15
PARASITE CONCENTRATION IN PRIMARY AND SECONDARY SLUDGE AS COMPARED TO TREATED SLUDGE (25)

Parasite	Type of Sludge*	Number of Viable and Nonviable Eggs/Kg Dry Weight of Sample	
		Average	Percent Viable Eggs
Ascaris spp. (human and pig roundworm)	Primary and Secondary	9,700	45
	Treated	9,600	69
Trichuris trichiura (human whipworm)	Primary and Secondary	800	50
	Treated	2,600	48
Trichuris vulpis (dog whipworm)	Primary and Secondary	600	90
	Treated	700	64
Toxocara spp. (dog and cat roundworm)	Primary and Secondary	1,200	88
	Treated	700	52

* Primary and secondary sludges include sludges from primary clarification, Imhoff digestion, activated sludge, contact stabilization, and extended aeration. Treated sludges include sludges from mesophilic aerobic and anaerobic digestion, vacuum filtration, centrifugation, lagoons, and drying beds.

through common sludge stabilization processes. The level of pathogen reduction achieved during sludge treatment varies with the process used and numerous other variables (e.g., time, temperature, pH, etc.). Detailed studies of the mechanisms of virus inactivation during sludge treatment have shown ammonia and detergents play a significant role. Drying and loss of moisture from sludge can result in significant inactivation of viruses. There is a 4 to 5 $\log_{10}$ decrease in virus numbers when the final sludge solid is above 90%. Dewatering causes the release of viral RNA and inactivation appears to be due to the dewatering process itself (34).

In sludge composting, sludge is mixed with other organic materials such wood chips or leaves, and is allowed to decompose for a period ranging from 3 to 4 weeks. Aerobic conditions are maintained either by pumping air into the compost pile, or by regularly turning the pile. Composting, being a thermophilic process with temperatures ranging from 60° to 70°C under ideal conditions, generally results in inactivation of pathogenic microorganisms. Protozoan cysts, helminth eggs, and pathogenic bacteria are effectively inactivated during this process. Experiments with model viruses (bacterial virus f2) have revealed that a properly operated Windrow compost system may result in total virus inactivation in approximately 50 days. Enteric virus monitoring of a windrow compost system has revealed their presence during the windrow phase, but none after the curing period (1).

Recent studies have also been conducted on the concentration of helminth in domestic sludges in the United States. Significant numbers of these parasites may survive both aerobic and anaerobic sludge treatment. As in the case of viruses, sludge drying (i.e., loss of moisture) has a great influence on the inactivation of parasites in sludges (30).

Radiation processing of sludge by exposure to high-energy electrons produced by an electron accelerator or radiation sources appears to be highly effective against pathogenic microorganisms and helminths (8).

A.8 Survival of Pathogens Applied to Land

Survival of pathogens contained in sludge after the sludge is applied to the land is obviously an important consideration in deciding how long a period of time must be allowed after the last sludge application before permitting access to the people and/or animals, and the harvesting of crops intended for human consumption. In addition, pathogen survival may affect the possible contamination of surface or ground water. Factors known to influence bacterial and viral survival in the soil are listed in Table A-16.

Temperature is an important factor in the survival of bacteria and viruses. Their survival is greatly prolonged at low temperatures; below 4°C, they can survive for months or even years. At higher temperatures inactivation or die-off is fairly rapid. In the case of bacteria, and probably viruses, the die-off rate is approximately doubled with each 10°C rise in temperature between 5° and 30°C (24).

TABLE A-16
FACTORS THAT INFLUENCE THE SURVIVAL OF BACTERIA AND VIRUSES IN SOIL (11)

Factor	Bacteria	Viruses
Temperature	Longer survival at low temperature; longer survival in winter than in summer	
pH	Shorter survival time in acid soils (pH 3-5) than in alkaline soils	May indirectly affect virus survival by controlling their adsorption to soils
Cations		May also indirectly influence virus survival by increasing their adsorption to soil (viruses appear to survive better in the sorbed state)
Desiccation and soil moisture	Greater survival time in moist soils and during times of high rainfall. Survival time is less in sandy soils with lower waterholding capacity.	One of the most proven detrimental factors. Increased virus reduction in drying soils.
Sunlight	May be detrimental at the soil surface	
Antagonism from soil microflora	Increased survival time sterile soil	No clear trend with regard to the effect of soil microflora on viruses
Organic matter	Increased survival and possible regrowth when sufficient amounts of organic matter are present	Unknown

The survival of bacteria on plants, particularly crops, is especially important, since these may be eaten raw by animals or humans, may contaminate hands of workers touching them, or may contaminate equipment contacting them. Such ingestion or contact would probably not result in an infective dose of a bacterial pathogen; but if contaminated crops are brought into the kitchen in an unprocessed state, they could result in the regrowth of pathogenic bacteria (e.g., Salmonella) in a food material affording suitable moisture, nutrients, and temperature.

Pathogens do not penetrate into vegetables or fruits unless their skin is broken; and many of the same factors affect bacterial survival on plants as those in soil, particularly sunlight and desiccation. The survival times of bacteria on subsurface crops (e.g., potatoes and beets) would be similar to those in soil (2).

The survival of enteric bacteria on crops has been extensively studied, and reviewed. Reported survival times for common bacteria pathogens range from less than 1 day to 6 weeks.

Virus survival on exposed plant surfaces would be expected to be shorter than in soil because of the exposure to deleterious environmental effects, especially sunlight, high temperature, and drying. Reported survival time of viruses on crops is similar to those of bacteria, and likewise appears to support a 1-month waiting period after last wastewater application before harvest. Because of their exposure to the air, desiccation, and sunlight, protozoan cysts and helminth eggs deposited on plant surfaces would also be expected to die off rapidly.

Land application of digested sludges has shown little impact of bacterial contamination of ground water, provided that the ground water table is not too high and the soil is well drained (17)(36).

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APPENDIX B

EFFECTS OF SLUDGE APPLICATIONS TO LAND ON SOILS AND PLANTS

B.1 General Properties of Soils

Soil is a complex mixture of inorganic and organic constituents. The inorganic fraction may consist partially of clay minerals, other silicate minerals, oxides, and carbonates. The organic fraction usually contains both humic and nonhumic substances. The proportions and properties of inorganic and organic components in soils are a function of time, climate, topography, vegetation, and parent material. In a well-aggregated soil, soil particles and pore space usually constitute about 50 percent each of the volume. Optimum conditions for plant growth exist when the soil pore space is about half occupied by air and half by water. With respect to the solid phase, the texture of a soil is defined by the relative proportion of particles found in the sand (>0.05 mm), silt (0.002 to 0.05 mm), and clay (<0.002 mm) size fractions. Through use of a texture triangle (Figure B-1), a soil horizon containing a certain percentage of sand, silt, and clay is assigned a name, such as sandy loam, silt loam, silty clay loam, etc.

Clay minerals, one of the more important inorganic fractions of a soil, are composed of layered sheets of tetrahedrally and/or octahedrally coordinated cations. The sheets of Si tetrahedra and Al octahedra are present in a 1:1 or 2:1 configuration. Kaolinite is a typical 1:1 clay mineral while montmorillonite and vermiculite are typical 2:1 clays. When trivalent aluminum or iron (+3) is substituted for tetravalent silicon (+4) and divalent magnesium or iron (+2) for trivalent aluminum (+3), a permanent net negative charge results on the surface of the clay mineral. This negative charge is satisfied by surface retention of a cation such as H^+, K^+, Na^+, Ca^{2+}, Mg^{2+}, Al^{3+}, etc. The magnitude of the negative charge is measured by determining the cation exchange capacity (CEC), commonly expressed in meq/100 g. The CEC arising from isomorphous substitution is not pH-dependent. However, clay minerals possess some pH-dependent CEC, arising from the dissociation of hydroxyl groups (-OH) present at the edges of broken clay crystals. The ability of clay minerals to attract and retain cations is a very important property in soils.

Soil CEC will be discussed later in detail. In addition to CEC, additional properties of clays include a high surface area, the capacity to sorb metals and some organic compounds, and the ability to swell or shrink depending on water content.

Other silicate minerals are less important than the clay minerals, primarily because of their minimal CEC and low surface area. Included in this category are minerals such as quartz, feldspars, and amphiboles.

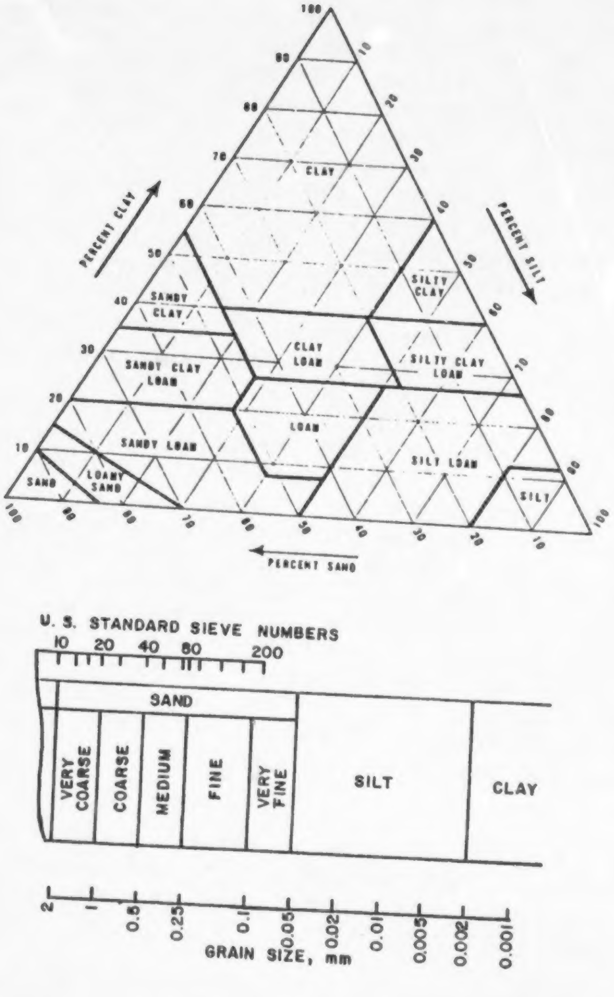

Figure B-1. Soil textural classes and general terminology used in soil descriptions.

The predominant oxide minerals are compounds of Fe, Al, and Mn. A significant part of the Fe and Al oxides in soils may be present as amorphous rather than crystalline compounds, depending on soil pH, organic matter content, and other properties. Amorphous compounds possess a higher surface area and greater chemical reactivity than their crystalline counterparts, and can sorb trace metals such as Cd, Cu, Ni, Zn, etc. It has been well established that Fe and Al compounds in soil are important sites for P fixation. The solubility of Fe^{3+} and Al^{3+} in soils is depressed with increasing pH. Since Fe and Mn can undergo oxidation-reduction reactions, the forms and subsequent solubility of Fe and Mn are influenced by soil aeration. Both Fe and Mn are more soluble under reduced than under oxidized conditions.

The presence of alkaline earth carbonates in soil influence its pH and buffering capacity. The pH of soils which contain excess carbonate ranges from about 7.5 to 8.2 and is buffered at this level until carbonates dissolve and leach downward in the soil profile. This results in soils becoming acidic, and additional liming materials (limestone) may have to be applied to promote crop growth, or, in the case of sludge application, to maintain a pH at or above 6.5.

Organic matter is another important component of soils (i.e., humus). There are two major categories of soil organic matter, namely, humic and nonhumic substances. Nonhumic substances are the intact or partially degraded compounds from plant, animal, or microbial residues. In general, non-humic substances account for less than 25 percent of soil organic matter. With time these constituents decompose, and a portion of the degradation products becomes incorporated into humic substances.

Humic substances are complex, high-molecular weight organic materials that result from chemical and enzymatic reactions of organic degradation products from plant, animal, and microbial residue. Humic substances are subdivided into the following categories: fulvic acids (acid and alkali soluble), humic acids (acid insoluble, alkali soluble), and humin (acid and alkali insoluble). Although quantitative differences exist in chemical composition, all three fractions are characterized by a nonpolar (aromatic rings) core with attached polar functional groups. The nonpolar nature of humics accounts for the strong affinity of soil organic matter for added organic compounds such as herbicides, pesticides, etc. Functional groups found in soil organic matter include carboxyl (-COOH), phenolic and alcoholic hydroxyl (-OH), amino ($-NH_2$), and sulfhydryl (-SH) groups. All of these functional groups exhibit acid-base character, and soil organic matter is thus involved in the buffering of soil pH. Furthermore, the ionization of the weakly acidic functional groups results in soil organic matter possessing a net negative charge or CEC. Soil pH strongly influences the CEC of soil organic matter with increasing pH resulting in increasing CEC. Metals may also interact with functional groups through chelation and ion exchange mechanisms. Clay minerals and organic matter account for virtually all soil CEC. The CEC of soil organic matter normally ranges from 100 to 300 meq/100 g, whereas the CEC of clay minerals varies, according to the mineral type, from 5 to 170 meq/100 g. Therefore, the relatively small fraction of organic matter present in a soil may exert a large influence on total CEC.

A more comprehensive treatment of the items discussed under general properties of soils can be obtained from a number of text books on the subject (5, 14).

B.2 Nitrogen Transformations

A simplified schematic of the nitrogen cycle is shown in Figure B-2. Both organic and inorganic nitrogen are added to soils by sludge addition. While the inorganic nitrogen (NH_4^+ and NO_3^-) is readily available for plant uptake, the organic nitrogen is not and must be converted to inorganic forms to render it plant available. The rate at which organic nitrogen is mineralized to plant-available inorganic nitrogen is highly variable, and depends upon the physical and chemical properties of the sludge applied, the physical and chemical properties of the soil to which the sludge is applied, the temperature, and the water content of the soil. Laboratory studies for net nitrogen mineralization rates during the first growing season for different sludge types showed rates which range from no net mineralization of the applied organic N (wet air oxidation treated) to 58 percent (waste-activated sludge) (30). In general, N mineralization rates were greatest for undigested primary and waste-activated sludges and least for composted and heat treated sludges. Essentially no net mineralization occurred where the carbon-to-nitrogen (C/N) ratio of the sludge was greater than approximately 20.

Important soil properties influencing the mineralization rate of organic nitrogen include temperature, water content, soil pH, and C/N ratio. For mineralization, soil-water content of approximately 50 percent of the water-holding capacity of the soil, soil pH values between 4.5 and 9.0, and C/N ratio in the amended soil less than about 20, are optimum. Carbon-to-nitrogen ratios of the soil-sludge mixture of about 10 or less are optimum for maximum N mineralization. In many sludge treated forest soils the rate of nitrification may be very slow, presumably because these soils frequently have low soil pH and C/N ratios much greater than 20. Likewise, the rate of nitrification of sludge treated drastically disturbed acid soils may be slow if the pH remains less than 4 following sludge application.

Because of the wide variety of factors affecting nitrogen mineralization rates for sludge applied to soil, it is advisable to determine rates on a site- and sludge source-specific basis. As a guideline, for agricultural soils, nitrogen mineralization rates, expressed as percent of sludge organic N, are given in Table 6-7 (the "F" factor).

Ammonium-N (NH_4-N) is a nitrogen compound added to soils in liquid sludge applications. It may be held on the clay surface as an exchangeable cation. In soils containing micaceous minerals, NH_4^+ may penetrate between the mineral plates, causing collapse of the mineral and NH_4^+ fixation. This form of NH_4-N is less reactive than exchangeable and

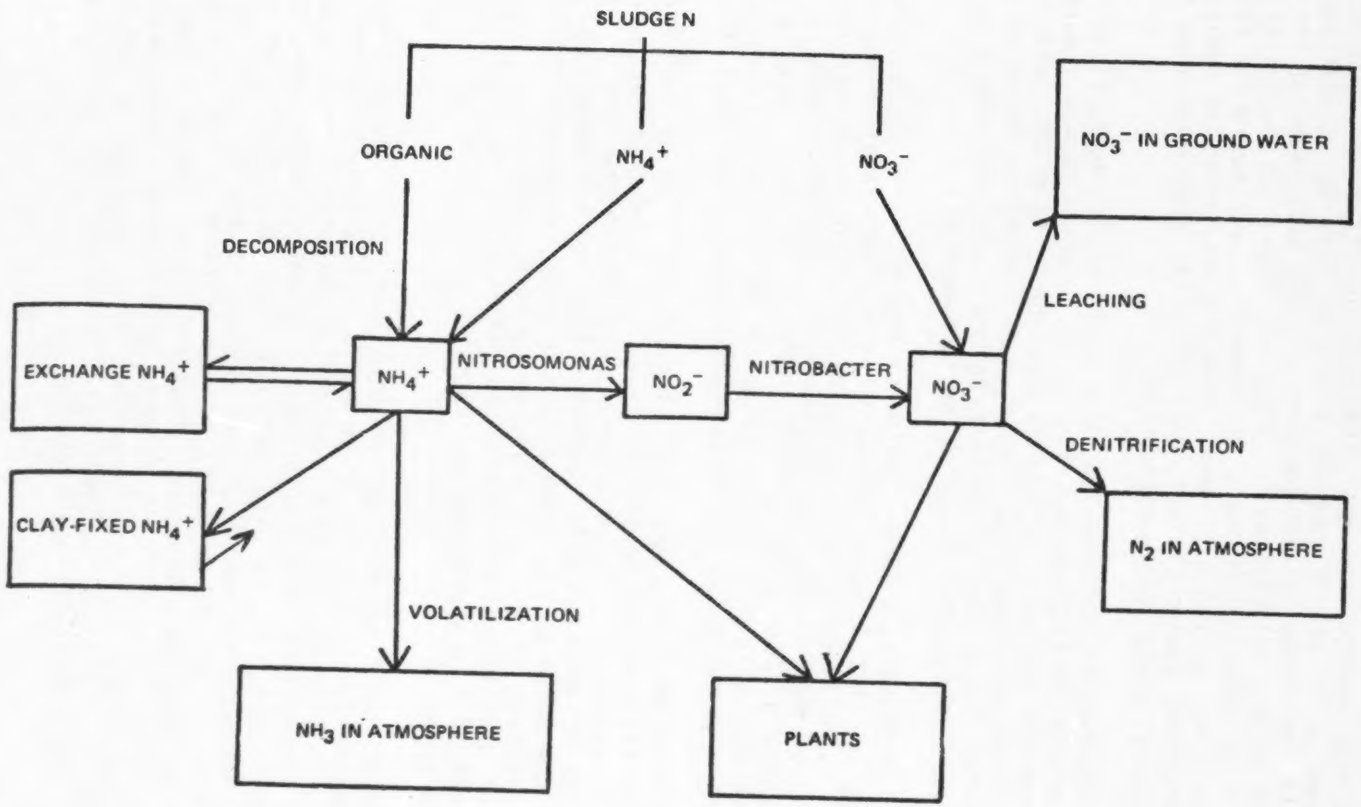

Figure B-2. Nitrogen cycle in soil.

soluble forms, but does in time undergo chemical and microbial transformations.

Of importance, especially when considering surface application of sludges, is NH_3 volatilization. In situations where liquid sludges are applied and not incorporated into the soil by injection, disking, or plowing, essentially all of the NH_4-N may be lost by volatilization. Even where liquid sludge is incorporated into the soil, some of the NH_4-N may be lost by NH_3 volatilization (28). The extent of NH_3 volatilization can not be generalized since it depends on any number of factors including soil pH, soil CEC, climate (temperature, relative humidity), and soil conditions (water content, rate of infiltration) and time lapse between application and incorporation (30).

Laboratory experiments indicate that the extent of NH_3 volatilization is related inversely to CEC and directly to pH. Unfortunately, quantitative data are not available concerning the magnitude of NH_3 volatilization under field conditions. At present, recommendations based on N application rates assume that 50 percent of the plant-available N is lost via NH_3 volatilization when sludge is surface-applied.

After addition to soil, a large portion of the NH_4^+ will be converted to nitrate (NO_3^-). This process, called nitrification, involves two steps. First, NH_4^+ is oxidized to NO_2^- by the bacterium Nitrosomonas, followed by oxidation of NO_2^- to NO_3^- by Nitrobacter. In neutral aerated soils at temperatures greater than 15°C, essentially all NH_4^+ added will be converted to NO_3^- within 2 to 4 weeks after application. Depressed nitrification rates may occur in soils at temperatures less than 10°C.

The formation of NO_3^- is significant, because NO_3^- can be lost from the soil through leaching and denitrification. In humid regions, N applied to soils in excess of crop requirements can leach and result in NO_3^- contamination of ground water. Systems developed for land application of sludges are based on the premise that a growing crop will reduce the NO_3^- concentration in the soil solution to levels which will result in minimal environmental risks. Thus, in agricultural applications, the annual amount of N in sludge applied to soils is based on the N required by the crop grown.

In addition to leaching, NO_3^- may be lost from soils through denitrification. Denitrification occurs when facultative anaerobic bacteria utilize NO_3^- as a terminal electron acceptor in place of O_2 under anaerobic conditions in the soil, i.e., saturated or excessive water contents. In an "aerobic" soil, it is also possible that denitrification can be occurring, because the center of soil aggregates may be water-saturated and anaerobic. The end products of denitrification are N_2O and N_2, which diffuse into the atmosphere. Denitrification may be a significant mechanism for N loss in soils treated with liquid sludge because of localized increases in soil H_2O content. Thus, NH_4^+ may be oxidized to NO_3^- in an aerobic zone, followed by diffusion of NO_3^- into anaerobic microsites where denitrification occurs.

Certain adverse effects of overfertilization of soils with sewage sludge may occur. The use of excess N can cause luxury consumption of NO_3^- by many plants, resulting in potential animal health problems when high NO_3^- feedstuffs are consumed. The leaching of NO_3^- from the soil profile could contaminate ground waters. Also, excessive nitrogen fertilization may cause lodging of small grains resulting in harvesting problems and reduced productivity.

The two areas of concern involving high concentrations of NO_3^- in waters are direct health effects and surface water eutrophication. Excessively high levels of nitrate-nitrogen in drinking water may present a health hazard. Winton, Tardiff, and McCabe described the circumstances which may induce methemoglobinemia or cyanosis in infants (35). The main controlling factor in this disease is the daily nitrate intake; hence, the nitrate concentration of drinking water plays an important role. Drinking water standards in the United States specify the maximum permissible concentration of nitrate-nitrogen as 10 mg NO_3-N/l.

Livestock may suffer from a number of symptoms caused by excessive nitrate-nitrogen levels in the drinking water, including vitamin A deficiency, reproductive difficulties and depressed milk production. Increased concentrations of N in surface water may also cause eutrophication, i.e., nutrient enrichment. Eutrophication results in rapid growth of the nuisance aquatic plants, most commonly phytoplankton blooms. The exact factors responsible for eutrophication are still insufficiently understood; however, P concentrations below 0.01 mg/l and N concentrations below 0.2 to 0.3 mg/l appear to minimize algal blooms in surface waters.

B.3 Phosphorus Interactions

The behavior of phosphorus in soils is controlled by chemical rather than biological reactions. The interactions of the phosphorus cycle are illustrated in Figure B-3. The majority of phosphorus in sludges is present in inorganic compounds, about 70 to 90 percent of the total phosphorus. Even though mineralization of the organic phosphorus occurs during decomposition, inorganic reactions of phosphorus are of greater importance in sludge application.

The available P for plants is present in the soil solution. As plants deplete the soil solution P, the equilibria with sorbed P and P minerals are shifted, resulting in replenishment of the soluble P pool. Thus, the concentration of soluble P in soils may not be related to the ability of a soil to supply P to crops throughout the entire growing season. Soils possess the ability to "fix" P through sorption and/or precipitation reactions. As a result, a concentration of <0.1 mg P/l in the soil solution generally results in minimal leaching losses of P. It has occasionally been inferred that excess P in the soil impairs plant growth via indirect action. For example, symptoms of Zn deficiency can be traced to P inhibition at the root surface when soluble phosphates are present. However, sludge applications add both P and Zn to minimize any potential P-Zn interactions.

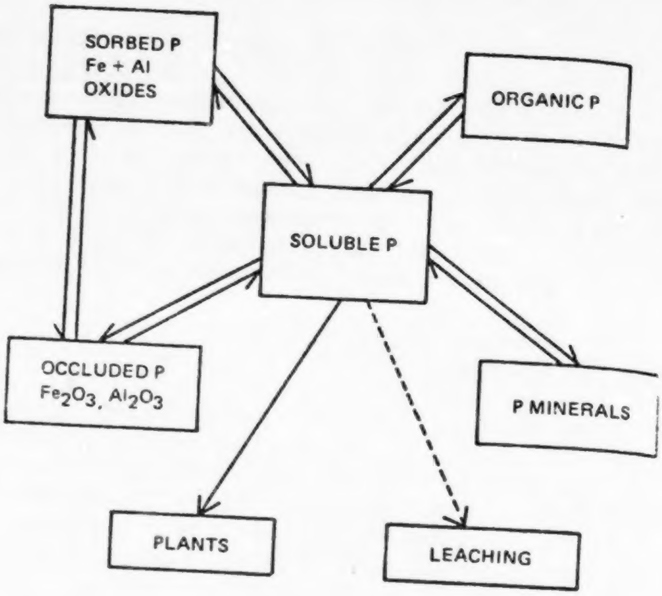

Figure B-3. Phosphorus cycle in soil.

B.4 Reactions of Metals in Soil

Land application of sludges will add appreciable amounts of trace metals to soils. The metal content of soils and plants is quite variable depending on the soil type and plant species. Trace elements such as B, Co, Cu, Mn, Mo, Fe, and Zn are essential for plant growth; however, if excessive concentrations are applied to soil, metal toxicities may develop and crop yields may decrease. Often, the interpretation of metal toxicity to plants is not straightforward because of interactions between nutrients, e.g., P-induced Zn deficiency. Nonessential metals, e.g., Cd, Ni, under certain conditions may be harmful to plants and decrease yields. Of greater concern is the enrichment of food chain crops with metals potentially harmful to humans and animals (As, Cd, Pb, Hg). Because As, Pb, and Hg are not taken up by most plants from soils, the element of greatest concern is Cd. In general, the rationale of sludge application guidelines is to minimize phytotoxicity and decreased crop yields caused by metal additions to soil, and excessive concentrations of nonessential metals, e.g., Cd, in the plant part consumed by man or animals. The fate of sludge metals in soils and plants has been examined in a number of review articles (8, 9, 20, 22).

The chemistry of metals in soils is quite complex and difficult to predict. The fate of metals added to soils in sewage sludge is depicted in Figure B-4. Metals available to plants and susceptible to leaching are present in the soil solution as the free metal ion (M^{2+}), complexes (MOH^+, MCl^+, etc.) and chelates (M-Fulvic acid, etc.). As plant uptake or leaching occurs, the soil solution re-equilibrates with the solid phase, resulting in a relatively constant concentration in the soil solution. The equilibrium concentration will be controlled by soil properties such as pH, Eh, and solution composition. In general, the solubility and plant availability of most metals decrease with increasing pH.

Metals in the soil solution are continuously interacting: forming precipitates (carbonates, hydroxides, phosphates, etc.), interacting with soil organic matter, being sorbed by clay minerals, and being retained by hydrous oxides. Furthermore, the properties of clay minerals in soil are influenced to a great extent by interaction with organic matter and hydrous oxides. In general, the organic matter complexed with clay is more resistant to decomposition than "free" organic matter, resulting in the clay and organic matter contents of soils increasing proportionately. The presence of acidic functional groups in soil organic matter is responsible for metal retention through both exchange and chelation mechanisms. Considerable evidence is accumulating concerning the importance of metal retention by Fe and Al hydrous oxides. Even where hydrous oxides are sorbed onto clay minerals, they still retain the ability to sorb metals. The Fe and Al hydrous oxide content of soils also tends to increase with increasing clay content.

The trace metal retention capacity and CEC of soils both tend to increase as the clay, hydrous oxide, and organic matter contents increase.

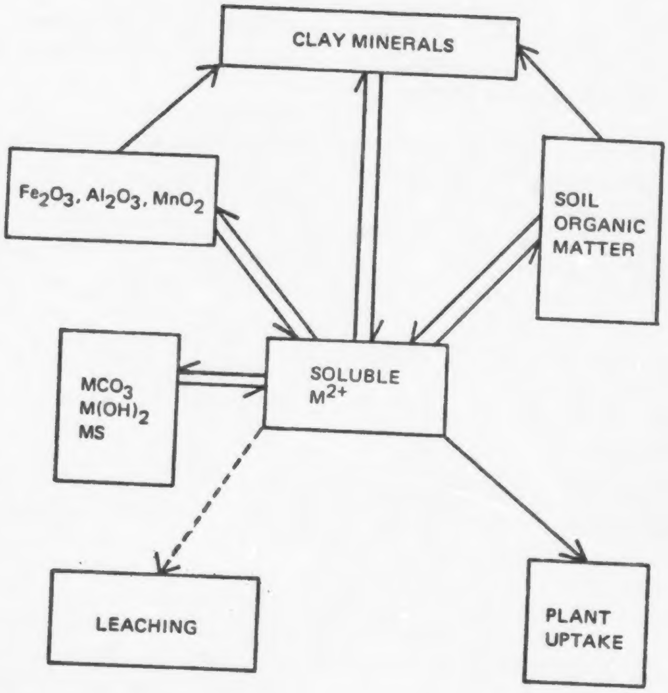

Figure B-4. Reactions of metals in soil (M^{2+} represents Cu, Zn, Ni, Cd, Pb, etc.).

Because of these relationships, the CEC has been used as an index of the metal retention capacity of a soil. This does not imply that metals added to soils are retained through an ion exchange mechanism. Metals present in soil as exchangeable cations are available for plant uptake, but only a small fraction of metals added to soil are present as exchangeable ions.

B.5 Trace Element Phytotoxicity and Plant Accumulation

Trace elements are ubiquitous in the geochemical environment. Their concentrations in soils vary widely, and depend upon the chemical composition of the parent material, degree of mineral weathering, and soil texture. In terms of their phytotoxic effects, the amounts present in plant-available form are seemingly more important than the total quantity in soils. The soil pH is the most important factor influencing the availability of trace elements to plants. Except for Mo, the availability of trace elements for plant uptake increases as the pH of the soil decreases. Consequently, trace element phytotoxicities and accumulation by plants are much more common on acid than neutral, alkaline, or calcareous soils. Plant species differ markedly in their tolerance to trace elements. Therefore, it is not possible to develop criteria associated with levels in soils that are applicable to all plant species.

Trace element accumulation may cause reduced crop yield or may pose health hazards to animals, including man, who may consume the crop. Trace elements identified as potentially harmful to plant growth or as elements whose concentration in crops may reach levels considered to be hazardous to humans and animals include: Al, As, B, Cd, Cr, Cu, Fe, Pb, Hg, Mn, Mo, Ni, Se, Sb, and Zn (33). In general, only Cd, Cu, Mo, Ni, and Zn are considered to pose a potentially serious hazard to either crops or the food chain (8). The remaining elements when applied to soil in the form of sludge are considered to pose relatively little hazard to crops and the food chain.

B.5.1 Manganese, Iron, and Aluminum

The concentrations of manganese in most soils, and Fe and Al in virtually all soils, far exceed concentrations which may be applied from sludges. Toxicities of Al and Mn occur only in acid soils, and are related to the concentrations of these elements in the soil solution. Where plants suffer from either Mn or Al toxicity, the condition is easily corrected through liming the soil to pH greater than 5.5. Iron is considered to pose potential problems only when it occurs in elevated levels in an active form and induces a deficiency of other essential elements (P, Mn). Because current regulations require that the pH of the sludge-treated soils used to produce food chain crops (except forest) be maintained at levels of 6.5 or greater, Al, Fe, and Mn should pose no hazard.

B.5.2 Chromium

Total chromium in soils usually varies from 50 to 3,000 mg/kg, with typical levels being about 100 mg/kg (22). The Cr naturally present in soils is quite inert. Most crops (except for a few indicator plants) grown on soils which contain high levels of Cr do not appear to absorb Cr much in excess of those grown on soils low in Cr. The two principal oxidation states of Cr are Cr(III) and Cr(VI) forms. The Cr(III) form is most common in soils, and when Cr(VI) (as $CrO_4^=$ and $Cr_2O_7^=$) is added to soils, it is rapidly reduced to the Cr(III) form. Cr(VI) in soils is absorbed by plants, and has been shown to be phytotoxic (26). The phytotoxic effect, however, is temporary and related to the rate at which Cr(VI) is reduced to Cr(III). Studies involving cropland application of sewage sludge containing substantial quantities of Cr have not resulted in reduced crop yield, or substantially increased the concentration of Cr in plant tissue (10). Based on available information, it is doubtful that Cr added to soil from sludges will damage crops, and no problems have been reported in the literature.

B.5.3 Arsenic and Antimony

Inorganic arsenicals have been used as insecticides and herbicides for many years, and certain soils have been seriously contaminated with these elements. Inorganic arsenical pesticides were banned in the United States in 1967 and have been replaced by the organic arsenicals (monosodium methanearsonate, disodium methanearsonate, and cacodylic acid). Most information on the potential detrimental effects of As in soils comes from the study of sites highly contaminated by pesticide use. Soils of apple and pear orchards where trees have been treated repeatedly with large amounts of arsenical pesticides contain sufficient As to damage many plant species (3). The residual As in the contaminated soils where phytotoxicities were observed was usually greater than 100 kg As/ha, and in many cases was greater than 200 kg As/ha. However, phytotoxicity was not necessarily directly related to the total As present in the soil, but to available Fe, Al, Ca, organic matter, soil texture, and susceptibility of the plant variety. Phytotoxicities associated with As are more likely to occur in coarse-textured soil with a low capacity to adsorb As. When grown on these soils, legumes have been shown to be sensitive to elevated levels of As in the soil. Rye and sudangrass, on the other hand, were quite tolerant. The concentrations of As in sewage sludge range from 3 to 30 mg/kg (see Appendix A, Table A-6). If one assumes a concentration of 25 mg As/kg sludge and 100 kg As/ha to cause phytotoxicity, 4,000 tons of sludge would have to be applied before levels in soil associated with phytotoxicity are reached. It is doubtful, therefore, that As levels in sludge-treated soils would reach potentially harmful levels unless sludge were applied continuously at high rates for about a century. The amounts of As absorbed by plants grown on sludge amended soils are not considered to be sufficiently great to present a hazard to consumers.

Concentration ranges of Sb common to natural soils are not well established. In the earth's crust, concentrations are usually less than 1 mg Sb/kg. Concentrations of Sb in sewage sludges from 16 cities in the United States vary from 2.6 to 44.4 mg Sb/kg sludge, with a median concentration of 10.8 mg Sb/kg (12). These concentrations are quite similar to concentrations of As which occur in the same sewage sludges. Because the chemistry of Sb is quite similar to that of As, and their concentrations in sewage sludges are approximately the same, a phytotoxic problem produced by Sb is also highly unlikely.

B.5.4 Lead and Mercury

Lead is a nonessential element which typically occurs in soils at a mean concentrations of 10 to 15 mg Pb/kg of soil (22). It has been applied to soils in very large amounts (greater than 500 kg/ha) with no apparent phytotoxic effects (2, 29). Soluble forms of Pb added to soil rapidly react with other chemical constituents in soils to form quite insoluble compounds; hence, leaching of Pb through soils to ground waters is unlikely. Typically, Pb concentrations of sludges are substantially greater than in soils; with repeated applications, enrichment of surface soil with Pb occurs. When ingested in excessive quantities by humans, Pb is highly toxic. However, it is unlikely that Pb applied to soil with sludges will be absorbed by plants and subsequently by humans. A number of cases of lead poisoning of large animals caused by the ingestion of forage and soil particles contaminated by industrial emissions of Pb have been reported (6, 13). Since repeated applications of sludges may cause substantial enrichment of surface soils, care should be taken to ensure that foraging animals avoid excessive consumption of soil.

Mercury, like Pb, can be harmful to the health of human beings when excessive amounts are ingested. Although aboveground parts of plants can be injured by Hg vapor, there is no evidence linking soil-applied Hg to phytotoxicity. Crops absorb only trace amounts of Hg through their root systems, therefore Hg absorption by plants grown on sludge amended soils is of little concern.

B.5.5 Selenium and Molybdenum

Selenium concentrations of sludges are frequently below levels detected by routine analytical procedures. Therefore, data for the Se content of sludges are not readily available. Its concentration in soil normally ranges from 0.1 to 2 mg Se/kg, with the typical level being 0.2 mg Se/kg. Although Se applied to soils is readily absorbed by crops, it does not appear to adversely affect crop growth.

Plants tend to respond to Mo applications to soils in a manner similar to their response to Se. It has been reported that large quantities of Mo may be added to soils with little effect on growing plants (18).

Elevated concentrations of Mo and Se in foods are not considered harmful to the health of human beings. High concentrations in livestock feed, however, can be harmful to the health of animals. A number of crops grown in soils high in Mo and Se will absorb sufficient amounts of these elements to cause either impaired health or metabolic imbalance in animals that consume the plants.

As a micronutrient element, Mo is required in small amounts by plants, and is also essential at low concentrations in the diet of animals. In animal diets, particularly of ruminant animals, concentrations of Mo as low as 5 mg Mo/kg may be toxic (1). The occurrence and severity of Mo toxicity are directly related to the amounts of Mo ingested relative to that of Cu and SO_4. High Mo and low Cu levels in forage constitute the most serious combination. In fact, Mo toxicity, molybdenosis, is frequently referred to as an Mo-induced Cu deficiency. It is not possible to specify levels of Mo in soils that would produce forage unfit for animal consumption, because the amounts of Mo absorbed by crops vary with soil properties. Generally, the availability of Mo to crops increases as the pH of the soil increases; the availability of Cu to crops usually decreases as the pH of the soil increases. Molybdenum toxicity to livestock animals is therefore more commonly associated with forage grown on alkaline soils.

Sewage sludge contains Mo in amounts which range from 5 to 39 mg/kg, with typical levels being 28 mg/kg. Although repeated applications of sludge to soils might potentially produce forage unfit for consumption by livestock, no reports of this effect appear in the literature. For Mo toxicity to develop in animals, high Mo and low Cu forage must be their sole source of feed. Since it is unlikely that feed from sludge-treated soils would comprise the entire diet of an animal, the possibility of Mo toxicity to animals traced to forage grown on sludge-treated soils seems remote.

While Se is not considered to be essential for the growth of higher plants, it is required in small amounts in the diet of animals. Like Mo, the margin between Se deficiency and toxicity in animal diets is narrow. Malnutrition in animals, caused by deficient levels of Se in their diets, is frequently reported in the United States and other parts of the world. Levels in animal diets which range from 0.04 to 0.2 ug Se/g have been associated with a deficiency (1). Selenium deficiency levels depend upon the kind of animal and the type of diet. Selenium deficiency is frequently associated with a Vitamin E deficiency and correction of Se deficiency in lambs and calves has routinely involved injections of Se and Vitamin E.

In areas where soils are naturally high in Se, certain plant species are capable of accumulating Se to levels considered unsafe for animal consumption. Selenium levels in forage exceeding 4 mg Se/kg (oven-dry weight, 70°C) are considered potentially toxic (1). Concentrations of Se in soils normally range from 0.01 to 2.0 mg Se/kg soil. At comparable levels in soil, amounts of Se absorbed by plants grown on neutral and calcareous soils are usually greater than quantities absorbed by plants grown on acid soils.

The data base to quantify concentrations of Se in sewage sludge is too limited to be generalized. Published data on sludges from 16 metropolitan areas suggest that Se concentrations in sludges generally exceed those typically found in natural soil (12). Prolonged use of certain sludges on soils would therefore be expected to cause some Se enrichment to soil. However, no indication of sludge-borne enrichment of Se in soil leading to crop or animal health problems have been reported in the literature.

B.5.6 Copper and Nickel

The concentrations of both Cu and Ni in natural soils are highly variable. Because of their ubiquitous nature and common use, these elements are always present in sewage sludges.

Copper concentrations in soils range from 2 to 100 mg Cu/kg soil, with typical levels being 40 mg Cu/kg soil. Copper is essential to the growth of plants, and occurs in plants at concentrations which usually range from 5 to 20 mg Cu/kg. In acid soils which have naturally high levels of plant-available Cu, and in soils where Cu has been applied in large amounts, it can be phytotoxic. The tolerance of plants to Cu in soil, as with other elements, varies among species. It has been recommended that Cu additions to soil in the form of sewage sludge not exceed 125, 250, and 500 kg Cu/ha in soils with CEC's of <5, 5 to 15, and >15 meq/100 g, respectively (33). The input limits are recommended for soils maintained at pH >6.5.

Although chronic Cu poisoning may occur in animals under natural grazing conditions, the problem is related to the dietary intake of Cu as well as Zn, Fe, Ca, Mo, S, and Cd (1, 32). Also, it is not necessarily related to Cu intake from forage alone, since considerable quantities of soil material may be ingested by grazing animals, and contributions of Cu from this source may be substantial (15). Sheep appear to be the domestic animal most sensitive to excessive amounts of Cu in the diet (32). No instances of Cu poisoning of animals grazing on sludge-treated soils have been reported. However, because copper could accumulate in the surface of highly sludge-treated soils, it may be possible that animals could ingest sufficient Cu to cause toxicity.

Nickel contents of natural soils vary from about 10 to 4,000 mg Ni/kg, with typical levels being 40 mg Ni/kg (22). While Ni is not considered to be essential for the growth of higher plants, it is essential for the growth of animals. Like Cu, Ni toxicities to plants normally occur only on acid soils. Yield reductions associated with Ni in the form of sludge applied to acid soils have been reported in England and the United States (25, 34). Although plant species vary markedly in their sensitivities to Ni concentrations in soil, levels greater than 40 kg Ni/ha in soils with pH values less than 5.5 may damage some crops such as oats, clover, potatoes, turnips, cabbage, and beets (25). Toxic levels for neutral, alkaline, and calcareous soils are much higher. For soils with pH values greater than 6.5, it has been recommended that Ni additions to soil in the form of sludge not exceed 125, 250, and 500 kg Ni/ha in soils with CEC's of <5, 5 to 15, and >15 meq/100 g, respectively (33).

Nickel is a relatively nontoxic element to animals, and Ni contamination of foods does not present a serious health hazard (32).

B.5.7 Cadmium and Zinc

Cadmium and Zn may reach phytotoxic levels under a wide range of soil chemical conditions. Plants grown on all soils appear to respond to the increased concentrations of these metals in soils with accelerated absorption. Cadmium and Zn phytotoxicity usually occurs at lower concentration levels in acid than in neutral or calcareous soils. Because Cd has the potential to present more problems in soils than other trace metals and Zn-Cd interactions and associations are common, these have been studied extensively.

Concentrations of Cd which occur in native soils normally range from 0.05 to 1.5 mg Cd/kg soil, with a typical level of 0.3 Cd/kg (23). Certain soils in California and elsewhere derived from shale parent material, however, contain unusually high levels of indigenous Cd (5 to 20 mg Cd/kg) (21). Although the Cd absorption characteristics of plants are not completely understood, available information shows that the concentration of Cd in the leaf tissue of plants tends to increase as the amount of Cd added to soil increases. The reproductive parts of plants (flowers, fruits, seeds) usually contain lesser concentrations of Cd, and respond less rapidly to Cd additions to soils than do vegetative parts. The phytotoxic tolerance of plant species to Cd added to soil and the amounts accumulated by various plant species are also highly variable.

Both the annual and cumulative total Cd input limits (0.5 to 2.0 kg Cd/ha, and 5 to 20 kg Cd/ha, respectively) that have been suggested for cropland application of sludges were intended to prevent elevated levels of Cd in food, and are much more conservative than levels associated with possible phytotoxicity. Available information indicates that the limits suggested by the EPA to stop the entry of Cd into the food chain are adequate to protect against Cd phytotoxicity to all crops.

The entry of Cd into the human and animal food chain from the use of wastewater sludges on agricultural land is considered by many to be the most critical problem related to the trace metal content of sludges. According to various estimates and surveys, the estimated daily dietary intake of Cd in the United States is approximately 1/3 to 1/2 of the maximum daily intake of Cd proposed by the Food and Agricultural Organization and the World Health Organization (36). Although there are no documented human health problems traced to sludge application to soils, there is clinical evidence from Japan that links Cd poisoning to the consumption of rice grown on soil contaminated by wastewater originating from nearby Zn smelting operations (31). Persons suffering from chronic Cd poisoning consistently derived a substantial percentage of their dietary rice from the contaminated fields, and consumed this rice daily for 30 to 50 years. Daily exposure to food containing elevated concentrations of Cd resulted in gradual accumulations in the bodies of the affected population so that symptoms of Cd toxicity later became evident. Preventive measures taken since the peak of the epidemic in the early 1950's have substantially reduced the number of new cases of Cd poisoning in the affected regions.

A number of studies in the United States and other parts of the world have shown that where sewage sludges containing Cd are applied to agricultural soils, the concentration of Cd in many crops grown on the sites is increased (7, 8, 9, 20, 22). However, the percent of cropland in the United States that has received sewage sludge is very small. Even if all sludges generated in the United States were to be used on agricultural soils as a source of nitrogen fertilizer, less than 1 percent of the agricultural land in the United States would be affected (8). Statistically, there is only a remote probability that any one person would consume foods elevated in Cd from the marketplace over a period of time sufficient to cause excessive exposure. However, misuse of sludge containing relatively high concentrations of Cd could conceivably lead to excessive Cd in food, and subsequent health problems.

Typical levels of Zn in soils are 50 mg Zn/kg. Zinc is an element essential for the growth of plants, and deficiencies of plant-available Zn in soil are frequently encountered. Sludge applications could therefore be beneficial in correcting Zn deficiencies in some soils.

Although high concentrations of Zn in any soil could result in phytotoxicities, the occurrence and impact of Zn toxicity is most severe for plants grown on acid soils. Suggested limits for Zn application to soils from sludge application are 250, 500, and 1,000 kg Zn/ha for soils with CEC's of <5, 5-10, and >15 meq/100 g, respectively (33).

Among the divalent metals, Zn is of a relatively low toxicity. Chronic toxicity to man from dietary sources of Zn is highly unlikely (32).

B.5.8 Boron

Relative to the other trace elements discussed, the role of B in land application of sludge is somewhat unique. In wastewaters, B occurs largely in the form of undissociated boric acid H_3BO_3. Being uncharged, it passes through soils much more readily than do the other trace elements. Although B is essential for crop growth, when present in soil solutions at concentrations greater than 1.0 mg/l, it is highly toxic to many plants. The margin between levels considered essential to plant growth and those considered phytotoxic is usually very narrow. Plants grown on soils whose level of water-soluble boron is less than 0.04 mg

B/l often exhibit B deficiency symptoms while at concentrations in excess of 1.0 mg B/l, B is toxic to sensitive species (4, 11). The concentrations of B in saturation extracts from soils known to damage a wide variety of crops are quite well documented, and tolerance levels are readily available (27).

Although the other elements previously discussed (Cr, Fe, Mn, Ni, Cu, Zn, Se, Mo, As, Hg, Pb, Sb, Cd, and Al) all tend to accumulate in the surface of soils following application, B is only weakly adsorbed by soils, and readily passes through them with leaching water. In arid and semiarid regions, the B in the sludges may have an adverse impact on plant growth, but cumulative effects are not as marked as with the other trace metals. In humid and semihumid regions, rainfall is usually sufficient to leach applied B from the root zone to harmful levels.

Boron has a low order of toxicity when administered orally (32). The possibility that crops grown on sludge-treated soils would accumulate concentrations of B potentially harmful to animals and humans is highly remote.

B.6 Organics

The concentration of organics, such as chlorinated hydrocarbon pesticides and polychlorinated biphenyls (PCB's), can be elevated above background levels (<10 ppm) in sewage sludges from cities receiving wastes from industrial discharges of these organic compounds. The potential impact of organic compounds on land application practices has been discussed recently by Pahren, et al., and Jelinek and Braude (24, 19). Very little research has been conducted on the uptake of organics by crops growing on sludge-treated soils; the following discussion emphasizes data obtained from related experiments. Pesticide and PCB levels in sludges are shown in Table B-1.

In general, a minimal amount of pesticides is sorbed by plants and translocated to aerial parts. For example, the foliage of corn contains less than 3 percent of the dieldrin applied to soil, while the concentration in the roots is appreciably greater. Nearly all pesticides are relatively nonpolar molecules which are strongly bound by soil organic matter and to the surface of plant roots. Thus, the concentration of pesticides in root tissue does not result from typical uptake mechanisms where the molecule must permeate the membranes of root cells.

The uptake of PCB's has been evaluated using carrots as the test crop (16). Soils treated with Aroclor 1254 at 100 mg/kg produced carrots containing from 2 to 30 mg PCB/kg, depending upon the examined component of the PCB mixture. More significantly, 97 percent of the PCB residue was found in carrot root peelings, only 14 percent of the carrot weight. These results suggest that PCB's are not actually taken up by carrots, but are physically adsorbed on the surface of carrot roots. Additional evidence supporting the inability of plants to accumulate organics was obtained by Jacobs, Chou, and Tiedje, who grew orchardgrass and carrots in soils treated with 10 and 100 mg/kg of polybrominated biphenyls

(PBB's) (19). At these rates, the amount of uptake of PPB's was essentially nondetectable (20 to 40 ug/kg) in carrots, and nondetectable in orchardgrass. It should be emphasized that the rates used in these studies far exceed those expected from sludge application. In general, plants exclude the majority of organics added to soils, resulting in minimal impact on the quality of forages and grains. Furthermore, even though PCB's and related compounds resist microbial degradation, they are slowly decomposed after incorporation in soils.

TABLE B-1
PESTICIDE AND PCB CONTENT OF DRY SLUDGES (24)

	Range (mg/kg)		
Compound	Minimum	Maximum	Number of Sludges Examined
Aldrin*	ND†	16.2	5
Dieldrin#	<0.03	2.2	21
Chlordane*	3.0	32.2	7
DDT + DDD*	0.1	1.1	7
PCB's**	ND	352.0	83

* Examined in 1971.

† Nondetectable.

# Examined in 1971, 1972, 1973.

** Examined in 1971, 1972, 1973, and 1975.

A potential problem arising from organics in sludge is direct ingestion by animals grazing on forages treated with a surface application of sludge. Most organics are concentrated in fatty tissues and fluids (butterfat). Even though rains may remove the majority of sludge adhering to forages after a surface application of sludge, a sufficient amount of sludge may remain, resulting in direct ingestion of organics by cattle. For this reason, Pahren, et al., suggested that sludges surface-applied to grazed forages contain no more than 10 mg/kg of PCB's (24). This problem can be eliminated for sludges containing over 10 mg/kg PCB by incorporation of the sludge into the soil prior to planting forage crops.

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APPENDIX C

SAMPLING AND ANALYTICAL METHODS

C.1 General

This appendix provides guidance in selecting methods for sampling and analysis of sludge, soils, plants, ground water, and surface water as may be necessary for design and/or monitoring of sludge to land application systems. The person selecting methods should also consult with the cognizant regulatory agency and with knowledgeable individuals at the local University Agricultural Extension Service, since regulatory requirements and applicable methods for local conditions vary geographically.

As discussed in Chapter 11, and elsewhere in the manual, the type, number, frequency, etc., of samples and analyses necessary will vary widely between different projects. This appendix does not stipulate what should constitute the sampling and analysis program; rather, it discusses methods available if certain types of sampling and analysis are required.

C.2 Soils

C.2.1 Purpose of Soil Sampling and Analysis

Soils can be sampled and analyzed at potential sludge application sites as part of the site selection process (see Chapter 4). More extensive soil testing may be conducted after a final site(s) selection has been made in order to establish baseline data. In addition, soil monitoring is periodically conducted at many sludge application sites after sludge application has been initiated and the program is in full operation.

The purpose of soil testing prior to sludge application is primarily to help determine site suitability. The soil characteristics of interest usually include the following:

- pH; a soil pH of 6.5, or above, is desirable, and often required by regulatory agencies, to minimize migration of heavy metals.

- Lime requirement; if soil pH is too low, lime additions can be used to raise soil pH to a proper level. The soil can be tested to determine the quantity of lime required.

- Plant available nutrients, i.e., N, P, and K; existing soil nutrient levels which are plant available is useful information in calculating sludge application rates to the sludge application site when growing vegetation on the site.

- CEC; is an indication of the soil's ability to tie up heavy metals and prevent their migration. Regulations existing in 1982, use soil CEC as a guide in setting limits upon cumulative heavy metal loading in the sludge application to sites used for crops.

- Soil permeability and texture (particle size distribution); provides guidance in determining the site drainage characteristics. As discussed in Chapter 4 and Appendix B, it is generally desirable that a sludge application site is moderately permeable, i.e., not so impermeable as to cause surface moisture ponding and not too permeable which may result in rapid subsurface migration of sludge constraints.

- C:N ratio; it has been suggested that for forest soils, which often have a high C:N ratio, this ratio is useful in estimating the nitrogen storage capacity of the soil as it effects the sludge application rate calculation. See discussion in Chapter 7.

After the sludge application program is underway, it may be necessary or desirable to monitor the changes occuring in the soil characteristics of the application site. This is usually not done for typical agricultural utilization projects where sludge is applied to farmland at agronomic rates, or below. Nor is routine post sludge application soil monitoring usually done for forest land or land reclamation sludge utilization when a one-time application is used, or sludge applications are at low rates commensurate with vegetation nutrient requirements. Generally, periodic soil monitoring of the sludge application site is done primarily when one or more of the following situations exist:

1. The sludge contains significant quantities of one or more heavy metals or priority persistent organics. In this case, the soil concentration of the sludge constituents of concern can be monitored.

2. Heavy sludge application rates are used, as with a dedicated disposal site, and there is concern that the soil will become phytotoxic to vegetation grown on the site.

3. The cognizant regulatory agency requires certain periodic soil monitoring. For example, the regulatory agency may require annual pH analysis to ensure that the soil pH remains above 6.5.

4. Research purposes. If demonstration projects, test plots, etc., are being implemented, extensive soil testing is often conducted to increase knowledge of the interaction between sludge constituents and soil systems.

C.2.2 Soil Sampling Procedures

Soils expertise is required to conduct and interpret an adequate soil sampling program because of the potential variables involved, including horizontal and vertical soil variations, size of the application site(s), and the objectives of the soil sampling program. Advice should be obtained from the University Cooperative Extension Service, County Agricultural Agents, and/or others with expertise in sampling and analysis of soils in the sludge application site(s) locality.

The number and location of samples necessary to adequately characterize soils prior to sludge application is primarily a function of the spatial variability of the soils at the site. In heterogenous materials, such as mine spoils, an adequate determination of conditions may require sampling on a grid pattern of some 30 m (100 ft) over the entire site. Conversely, if the soil types occur in simple patterns sampling of each major type can provide an accurate picture of the soil characteristics. Often, existing soils maps (e.g., from the Soil Conservation Service) and field visual observations provide an indication of the variability, location, and extent of each major soil type at the site.

In some states, the state regulatory agency stipulates the minimum number of soil borings which must be analyzed. New Jersey, for example, stipulates the minimum number of soil borings required based on proposed sludge application site area, ranging from a minimum of 3 borings on small sites (up to 4 ha; 10 ac) to 24 borings on large sites (over 80 ha; 200 ac).

The depth to which the soil profile is sampled and the extent to which each horizon is vertically subdivided depend largely on the parameters to be analyzed, the vertical variations in soil character, and the objectives of the soil sampling program. Typically, samples are taken from each distinct soil horizon down to a depth of 120 to 150 cm (4 to 5 ft). For example, samples may be taken from four soil depths (horizons) as follows: 0 to 15 cm (0 to 6 in), 15 to 45 cm (6 to 18 in), 45 to 75 cm (18 to 30 in), and 75 to 120 cm (30 to 42 in). Usually, as a minimum, samples are at least taken from the upper soil layer, e.g., 0 to 15 cm (0 to 6 in), and a deeper soil horizon, e.g., 45 to 75 cm (18 to 30 in). Samples taken from similar soil horizons are usually composited for several borings located near each other in homogeneous soil. The composited samples are subsequently analyzed.

The proper selection of tools for soil sampling depends in part on the texture and consistency of the soil, the presence or absence of rock fragments, the depth to be sampled, and the degree of allowable surface soil disturbance. Soil samples are most accurately taken from a freshly dug pit. However, where field plots are to be sampled periodically, preferable sampling tools are those which disturb the plot the least. Cutaway soil sampling tubes, closed cylinder augers, and tiling spades (sharp-shooter) may be used depending upon the size of the plot and allowable disturbance. The cutaway soil sampling tube creates the least disturbance, and works well in the plow layer and the upper subsoil of moist, stone-free friable soils. Each sample collected should represent the cross section of the soil layer being sampled.

In sampling subsurface soils, care must be taken to remove loose particles or sludge residue on the soil surface around the hole prior to and during sampling. In addition, any surface soil/sludge residue attached to the top and side of the core samples from lower depths should be removed by slicing with a knife. It is recommended that the holes be sealed by filling with bentonnite pellets and tap water. A map showing samples points should be made.

C.2.3 Soil Sample Preservation

Samples should be air-dried (at temperatures less than 40°C), ground, and passed through a 2-mm sieve as soon as possible after collection. Chemical analyses are generally performed on air-dried samples, and do not require special preservation for most parameters. However, samples collected for nitrate, ammonia, and pathogen analyses should be refrigerated under field moist conditions and analyzed as soon as possible.

C.2.4 Soil Analysis

Table C-1 lists possible soil surface layer and subsurface parameters which may be of interest. Table C-2 lists methods which are used to extract the element of interest from soil. Table C-3 lists analytical methods for measuring chemical constituents of interest after extraction. Table C-4 lists methods, used to analyze soil physical properties. Table 6-9 in Chapter 6 presents suggested monetary requirements for sludge applied at agronomic rates for crop production.

C.3 Vegetation

Vegetation monitoring is usually only done if one, or more, of the following situations exist:

1. Heavy sludge application rates are used, as with a dedicated disposal site, and there is concern that food chain vegetation being grown on the site may be accumulating potentially harmful quantities of heavy metals (particularly Cd) from the sludge amended soil.

2. For public relations purposes, it is desirable to assure private owners of farms, tree farms, etc., that their crops are not being adversely affected by their use of sludge.

3. Research purposes, e.g., demonstration projects, test plots, etc.

TABLE C-1
POTENTIAL SOIL SURFACE LAYER AND SUBSURFACE PARAMETERS OF INTEREST

Prior to Sludge Application	
Surface Layer	Subsurface Layers
pH	pH
Electrical conductivity	Electrical conductivity
Lime requirement (acid soils)	Permeability
Plant available P and K	Particle size distribution (texture)
CEC	
Permeability	
Particle size distribution (texture)	
C:N ratio (forest lands)	
Monitoring After Sludge Application	
pH	pH
Electrical conductivity	Electrical conductivity
Moisture content	
Plant available P and K	
NH_4-N	NO_3-N
Organic-N	NH_4-N
Organic matter	
Permeability	
Particle size distribution (texture)	
Heavy metals (Cu, Ni, Pb, Zn)*	
Cd*	
Persistant organics (PCB, DDT, dieldrin, etc.)*	

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* If present in the sludge in significant quantity.

TABLE C-2
EXTRACTION METHODS FOR SOIL

Element	Method	Reference Number	Page
Nitrogen (N)	Total N: Kjeldahl digestion method	1	1162
	NH_4^+ (ammonium): extract with 2N KCl	1	1191
	NO_3^- (nitrate) and NO_2^- (nitrite): extract with 2N KCl	1	1191
Phosphorus (P)	Total P: digest in perchloric acid	1	1036
	Organic P: extraction with hydrochloric acid		1038
	Available P:		
	a) Extract with 0.03N NH_4F + 0.025N HCl	1	1040
	b) Extract with dilute HCl + H_2SO_4	1	1040
	c) Extract with 0.5M $NaHCO_3$	1	1040
	d) Extract with water	1	1043
Sulfur (S)	Total S: Johnson and Nishita digestion method	1	1104
	Organic S: a) Extract with 1N HCl b) Extract with 1N $Ca(OAc)_2$ c) Extract with water	1	1108
	Available S: Use extracting solution (39 g NH_4OAc [ammonium acetate] in 1 l of 0.25N acetic acid)	1	1112
Chloride (Cl^-)	Extract with water	2	193
Cation Exchange Capacity (CEC)	Extract with 1N NaOAc (sodium acetate)	1	899
Exchangeable Cations	Extract with 1N NH_4OAc (ammonium acetate)	1	903

TABLE C-2 (continued)

Element	Method	Reference Number	Page
Soluble Salts	Water saturation extract	1	935
Electrical Conductivity	Water saturation extract	1	935
pH	1:1 soil/water	1	920
Carbon (C)	Total C: digestion with 60:40 concentrated H_2SO_4/85% H_3PO_4	1	1350
	Organic C: a) 1N $K_2Cr_2O_7$ (potassium dichromate) b) Concentrated H_2SO_4 c) Water	1	1374
	Inorganic C: digestion with concentrated H_2SO_4 and $FeSO_4$ $7H_2O$	1	1386
Boron (B)	Extract with hot water	2	185
Aluminum (Al)	Extract with ammonium acetate (NH_4OAc) adjusted to pH 4.8	2	185
Arsenic (As)	Extract with: a) 0.5 N NH_4F b) 0.1 N NaOH c) 0.5 N H_2SO_4 d) 1N NH_4Cl	3	254
Cobalt (Co)	Extract with solution A (Na_2CO_3, 6N HCl, boiling water) and dithizone solution	1	1072
Selenium (Se)	Digest with nitric acid-sulfuric acid and mercuric oxide (HgO)	1	1118
Molybdenum (Mo)	Extract with anion exchange resin (Dowex-1-X4)	2	17
Heavy Metals (Cu, Zn, Mn, Fe, Ni, Pb, Cr, Hg, Sr, Cd, Sb, Ag, Ba)	Total: extract with strong acids (HNO_3-$HClO_4$, HNO_3-H_2SO_4, HCl-HNO_3)	1	*
	Available: DTPA;	7	84
	water, dilute HCl, 1N NH_4OAc (pH 4.8, pH 7.0)	1	†

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* Acids selected will depend on the metal(s) of interest.

† Different extractants have been used for a single metal or a group of metals. No single extractant is universally applicable to all metals.

TABLE C-3. ANALYTICAL METHODS FOR ELEMENTS IN SOLUTION

Measurement	Method	Std. Method Number (4)	Page
Acidity	Phenolphthalein or methyl orange titration	402	273
Alkalinity	Potentiometric titration	403	278
Arsenic (As)	Silver diethyl-dithio-carbamate method	404A	283
BOD	Dissolved oxygen determination	507	543
COD	Classical reflux method	508	550
Chloride	Potentiometric method	408C	306
Dissolved Oxygen	Membrane electrode method	422F	450
Hardness	EDTA titrametric method	309B	202
MBAS	Methylene blue method	512A	600
Metals:			
Calcium (Ca)	Atomic absorption	301A	144
Magnesium (Mg)	Atomic absorption	301A	144
Zinc (Zn)	Atomic absorption	301A	144
Copper (Cu)	Atomic absorption	301A	144
Cadmium (Cd)	Atomic absorption	301A	144
Mercury (Hg)	Flameless atomic absorption	315A	229
Nickel (Ni)	Atomic absorption	301A	144
Lead (Pb)	Atomic absorption	301A	144

TABLE C-3 (continued)

Measurement	Method	Std. Method Number (4)	Page
Chromium (Cr)	Atomic absorption	301A	144
Manganese (Mn)	Atomic absorption	301A	144
Molybdenum (Mo)	Atomic absorption	301A	144
Iron (Fe)	Atomic absorption	301A	144
Cobalt (Co)	Atomic absorption	301A	144
Aluminum (Al)	Atomic absorption	301A	144
Boron (B)	Colorimetric (Curcumin)	405A	287
Antimony (Sb)	Atomic absorption	301A	144
Nitrogen (N):			
N-ammonia 412	Distillation; nesslerization	418A, B	410,
N-organic	Kjeldahl digestion	421	437
N-nitrate	Electrode method	419B	422
N-nitrite	Colorimetric method	420	434
Oil and Grease	Soxhlet extraction	502D	519
pH	pH electrode	424	460
Phenolics	Distillation; chloroform extraction direct photometric	510A,B,C	576
Phosphorus (P)	Digestion; colorimetric	425C,D,E,F	474
Residue:			
Filterable	Glass fiber filtration, evaporation	208B,C	92
Nonfilterable	Glass fiber filtration	208D	94

TABLE C-3 (continued)

Measurement	Method	Std. Method Number (4)	Page
Total	Evaporation	208A	91
Volatile	Ignition method	208E	95
Settleable Matter	Imhoff cone method	208F	95
Selenium (Se)	Diaminobenzidine method	318A	238
Silica	Gravimetric method	426A	485
Specific Conductance	Conductivity measurement	205	73
Sulfide	Methylene blue or titrimetric method	428C,D	503
Turbidity	Nephelometric method	214A	132

TABLE C-4. PHYSICAL ANALYSIS FOR SOILS

Parameter	Method	Reference Number	Page
Particle Size Analysis	Hydrometer method/ sieving	1	545
Permeability:			
Soil-to-air		1	524
Soil-to-water		1	528
Aggregates (structure)	Dry sieve method	1	500

C.3.1 Plant Sampling Procedures

Plant tissue may be sampled during several growth stages, although mature leaves or stalks growing on main branches or stems are generally preferred. Table C-5 presents data indicating the portion of various plants typically sampled, and provides an indication of the number of separate leaves or stalks necessary for a representative sample. Portions of plants covered by dust or adhering soil, damaged by insects, mechanically damaged, or diseased should not be sampled.

The basic principles underlying plant tissue sampling are common to both forestry and agricultural crop species, but specific methodologies unique to foliar samples of tree species are given below (13):

- Sample conifer foliage during the dormant season.
- Sample deciduous leaves at maturity.
- Sample both dominant and codominant trees.
- Sample upper portions of the crown for foliage samples.
- Sample current-year foliage.
- Do not sample foliage or twigs bearing cones.

C.3.2 Plant Sample Handling and Preservation

All plant samples should be washed with deionized, distilled water before drying to remove any surface contamination unless the contaminant is of analytical concern. In some cases, it may be necessary to wash the plant samples with a detergent solution or a very weak acid solution before the final rinse with deionized water.

Samples should be dried (65°C maximum) as quickly as possible, finely ground, and stored for analysis. If the undried samples cannot be processed immediately, they should be placed in polyethylene bags and stored under refrigeration.

Prior to chemical analysis, the plant tissue sample(s) must be treated by one of three digestion methods to bring elements into solution. The methods of digestion depend on the element to be analyzed.

- Wet digestion - for all elements except nitrogen (N) and boron (B). Digest with nitric-perchloric (HNO_3-$HClO_4$) acids. Treatment with hydrofluoric (HF) acid may be necessary for recovery of some of the heavy metals from the silica which precipitates in the digest.

- Dry ashing - ash at low temperature (450° to 500°C). Dissolve ash in hydrochloric acid (HCl). This is the only method to be used for B analysis; not suitable for Hg, S, Se, As, Cu, Ag, Fe, Sb, and N.

- Kjeldahl (H_2SO_4) digestion - for total N, P, and K (see Reference (4), Page 1162, for procedure).

TABLE C-5
SUGGESTED PROCEDURES FOR SAMPLING DIAGNOSTIC TISSUE OF CROPS (2)

Crop	Stage of growth[a]	Plant part sampled	Number plants/ sample
Corn	Seedling	All the above ground portion.	20–30
	Prior to tasselling	Entire leaf fully developed below whorl	15–25
	From tasseling to silking	Entire leaf at the ear node (or immediately above or below).	15–25
Soybeans and other beans	Seedling	All the above ground portion.	20–30
	Prior to or during early flowering	Two or three fully developed leaves at top of plant.	20–30
Small grains	Seedling	All the above ground portion.	50–100
	Prior to heading	The 4 uppermost leaves.	50–100
Hay, pasture or forage grasses	Prior to seed emergence	The 4 uppermost leaf blades.	40–50
Alfalfa, clover and other legumes	Prior to or at 1/10 bloom	Mature leaf blades taken about 1/3 of the way down the plant.	40–50
Sorghum-milo	Prior to or at heading	Second leaf from top of plant	15–25
Cotton	Prior to or at 1st bloom, or at 1st square	Youngest fully mature leaves on main stem.	30–40
Potato	Prior to or during early bloom	3d to 6th leaf from growing tip	20–30
Head crops (e.g., cabbage)	Prior to heading	1st mature leaves from center of whorl.	10–20
Tomato	Prior to or during early bloom stage	3d or 4th leaf from growth tip.	10–20
Beans	Seedling	All the above ground portion.	20–30
	Prior to or during initial flowering	2 or 3 fully developed leaves at the top of plant.	20–30
Root crops	Prior to root or bulb enlargement	Center mature leaves.	20–30
Celery	Mid-growth (12–15" tall)	Petiole of youngest mature leaf.	15–30
Leaf crops	Mid-growth (12–15" tall)	Youngest mature leaf.	35–55
Peas	Prior to or during initial flowering	Leaves from 3d node down from top of plant.	30–60
Melons	Prior to fruit set	Mature leaves at base of plant on main stem.	20–30

[a] Seedling stage signifies plants less than 12 inches tall.

Table C-3 listed the specific analytical methods for elements in solution.

C.3.3 Plant Sample Analysis

It is not common to routinely monitor crops or other vegetation grown on sludge-to-land application sites. In those cases where plants are monitored, they are generally analyzed for selected heavy metals and/or plant nutrient content. Table C-6 presents a list of potential monitoring parameters for agricultural crops. Actual parameters monitored may vary from this list, depending on the sludge constituents of concern.

TABLE C-6. POTENTIAL CROP MONITORING PARAMETERS

A. Heavy Metals

- Cadmium
- Copper
- Molybdenum
- Nickel
- Zinc

C. Other Elements or Constituents*

- Antimony
- Arsenic
- Chromium
- Iron
- Manganese
- Mercury
- Selenium
- PCB's

B. Macronutrients (Optional)

- Nitrogen
- Phosphorus
- Potassium

* The other elements or constituents listed under C are analyzed only if there are significant quantities of those contained in the sludge being applied, and the crop may enter the food chain.

C.4 Ground Water Monitoring

Ground water monitoring may be required to ensure that the project is not contaminating useful ground water aquifers in the sludge application site or sludge storage area. Regulatory agencies often require ground water monitoring for dedicated sludge disposal sites, and may also occasionally require ground water monitoring for forest land or disturbed land sludge utilization over sensitive aquifers. Rarely is ground water monitoring required for projects using the agricultural utilization option, since by definition this option balances sludge application rates with crop nutrient requirements.

C.4.1 Ground Water Monitoring Design

If a ground water monitoring program is required, a hydrogeologist should be consulted during the initiation and implementation of the program. Detailed ground water monitoring procedures can be found in the U.S. EPA publication (EPA/530/SW-611) entitled, Procedures Manual for Ground Water Monitoring at Solid Waste Disposal Facilities (14).

Monitoring wells are constructed to provide representative ground water samples. The number of wells needed and their proper placement depends on the location of the water table and the direction of ground water flow. If several aquifers could be affected, a set of monitoring wells is required for each aquifer. The depth of the monitoring wells is dependent on the depth of the aquifer(s) being sampled, and the predicted pathway of potential migrating contaminants. A qualified hydrologist should be involved in making these decisions, based on specific geologic and hydrologic conditions at the site. Consideration should be given to such factors as the following (9):

- Soil and rock formations existing on the site.
- Direction of ground water flow and anticipated rate of movement.
- Depth of seasonal high water table, and an indication of seasonal variations in ground water depth and direction of movement. This should not be a problem with dewatered sludge or liquid sludge at agronomic rates.
- Nature, extent, and consequences of ground water mounding, which may occur above the naturally occurring water table.
- Depth of impervious layers.

It may be necessary to establish baseline site ground water conditions through installation of simple observation wells prior to the actual selection of locations and depths for permanent monitoring.

Generally, if monitoring is required, three or more monitoring wells are installed, as follows:

- One background well located upstream, and not affected or contaminated by sludge application.
- One or more (depending on site size and hydrogeological factors) wells located off-site downgradient from the site, and used to detect leachate migration.
- One or more on-site wells located in the zone of maximum leachate concentration.

Often, monitoring wells are installed during the site selection and/or design investigations. It is desirable to start monitoring 6 months to a year before any sludge applications to establish background ground water quality including any seasonal fluctuations.

Figure C-1 shows a typical monitoring well. Important features include an impermeable backfill, PVC piping, well screen, and gravel fill around the well screen. The composition of the materials selected for ground water monitoring well construction, sample collection and storage should be examined for possible contamination and interference with the chemical analysis. For example, galvanized pipe should not be used when testing for trace metals. Inert materials such as ABS or PVC reduce the possibility of erroneous readings, although the glues used on the fittings can also contaminate samples. Disinfection of wells, equipment, and containers by chlorination or other means is required if bacteriological examination is included (8). However, no residual chlorine must remain after disinfection or microbial counts will be reduced.

A dry drilling method (e.g., augering) is preferred for the construction of monitoring well boreholes, since it eliminates contamination of ground water with drilling mud and offers lower installation costs. Coring, with hollow- or solid-stem augers, and hydraulic rotary drilling are the most common dry and wet drilling methods, respectively.

The boreholes are normally backfilled by packing with gravel and sand around the screened area of the pipe. A low-permeability material, usually bentonite or a sand-bentonite mixture, is then packed to prevent surface water from channeling down the side of the casing. A concrete support is built around the above-ground portion of the well to protect it from damage or vandalism.

C.4.2 Ground Water Sampling Collection Methods and Frequency

Ground water sampling can be collected using a bail, air lift, submersible pump, or vacuum, depending on the analyses to be performed. For example, when sampling of ground water for reduced species (e.g., H_2S) the possibility of air contamination or O_2 injection into the sampling system. To the extent possible, collection techniques should remain consistent throughout the monitoring program.

Recommended precautionary procedures at the wells include the following (10):

- A measured amount of water equal to or greater than three times the amount of water in the well and/or gravel pack should be exhausted from the well before sample collection. In the case of very low-permeability soils, the well may have to be exhausted and allowed to refill before a sample is collected.

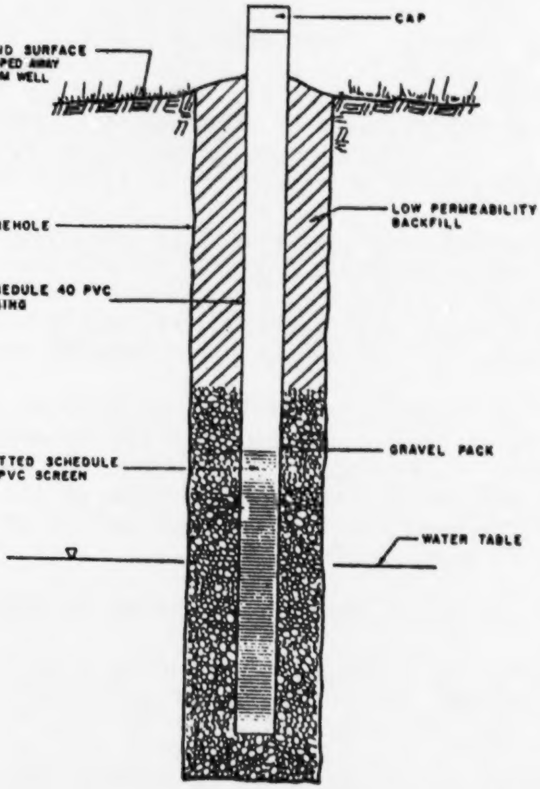
CAP
LAND SURFACE SLOPED AWAY FROM WELL
BOREHOLE
LOW PERMEABILITY BACKFILL
SCHEDULE 40 PVC CASING
GRAVEL PACK
SLOTTED SCHEDULE 40 PVC SCREEN
WATER TABLE

Figure C-1. Typical monitoring well screened over a single vertical interval.

- Pumping equipment should be thoroughly rinsed before use in each monitoring well. Water pumped from each monitoring well should be discharged to the ground surface away from the wells to avoid recycling of flow in high-permeability soil areas.
- Samples should be collected, stored, and transported to the laboratory in a manner to avoid contamination or interference with subsequent analyses.

The frequency of sample collection is dependent upon the goals of a particular ground water monitoring (i.e., whether it is long- or short-term). The estimated rate of pollutant travel in a given hydrogeologic setting will indicate intervals of time which will show a change in water quality. Careful analyses of the initial and later samplings may warrant adjustment of the sampling frequency. Arbitrary selection of sampling frequency may not reveal the true picture of ground water quality at the disposal site.

C.4.3 Ground Water Sample Preservation

It is impossible to maintain complete stability for every constituent in a water sample. Preservation techniques can only retard the chemical and biological changes that inevitably continue after the sample is collected. Table C-7 presents methods of preservation for water samples, volume required, container type, and storage time, as recommended by the U.S. EPA (6). Refrigeration at temperatures near freezing (2 to 4°C) is the best available preservation technique. Water pH should be determined on site, while other analyses should be made as soon as practical in the laboratory.

C.4.4 Ground Water Parameters

The constituents included in the analysis of ground water samples are dependent on such factors as monitoring goals, budgetary restrictions, waste composition, uses of ground water, regulatory requirements, etc. If the ground water involved is an actual or potential potable water supply parameters for which drinking water standards have been established should be measured (11, 12). If high concentrations of certain heavy metals, toxic chemicals, or fecal bacteria are present in the sludge, they should be included in the ground water monitoring list. No single list of parameters applies to all cases.

As an illustration of parameters which are often analyzed in ground water samples taken in connection with sludge application site(s) monitoring, the following list is presented:

- pH.
- Electrical conductivity and/or TDS.
- Total hardness.
- Alkalinity.
- Chlorides.

TABLE C-7
SAMPLE SIZE AND SAMPLE PRESERVATION[a] (6)

Measurement	Vol. req. (ml)	Container	Preservation	Holding time[f]	Standard Method Number[g]
Acidity	100	P,G[b]	Cool, 4°C	24 hrs	402
Alkalinity	100	P,G	Cool, 4°C	24 hrs	403
Arsenic	100	P,G	HNO_3 to pH < 2	6 mos	404
BOD	1,000	P,G	Cool, 4°C	6 hrs[c]	507
Bromide	100	P,G	Cool, 4°C	24 hrs	406
COD	50	P,G	H_2SO_4 to pH < 2	7 days	508
Chloride	50	P,G	None Req.	7 days	408
Chlorine Req.	50	P,G	Cool, 4°C	24 hrs	412
Color	50	P,G	Cool, 4°C	24 hrs	204
Cyanides	500	P,G	Cool, 4°C NaOH to pH 12	24 hrs	413
Dissolved Oxygen					402
Probe	300	G only	Det. on site	None	
Winkler	300	G only	Fix. on site	None	
Fluoride	300	P,G	Cool, 4°C	7 days	414
Hardness	100	P,G	Cool, 4°C	7 days	309
Iodine	100	P,G	Cool, 4°C	24 hrs	416
MBAS	250	P,G	Cool, 4°C	24 hrs	512
Metals					301
Dissolved	200	P,G	Filter on site HNO_3 to pH < 2	6 months	
Suspended					
Total	100		Filter on site HNO_3 to pH < 2	6 months	
Mercury					315
Dissolved	100	P,G	Filter HNO_3 to pH < 2	38 days (glass) 13 days (hard plastic)	
Total	100	P,G	HNO_3 to pH < 2	38 days (glass) 13 days (hard plastic)	
Nitrogen					417
Ammonia	400	P,G	Cool, 4°C H_2SO_4 to pH < 2	24 hrs[d]	418
Kjeldahl	500	P,G	Cool, 4°C H_2SO_4 to pH < 2	24 hrs[d]	421
Nitrate	100	P,G	Cool, 4°C H_2SO_4 to pH < 2	24 hrs[d]	419
Nitrite	50	P,G	Cool, 4°C	24 hrs[d]	420
NTA	50	P,G	Cool, 4°C	24 hrs	--
Oil & Grease	1,000	G only	Cool, 4°C H_2SO_4 to pH < 2	24 hrs	502
Organic Carbon	25	P,G	Cool, 4°C H_2SO_4 to pH < 2	24 hrs	505
pH	25	P,G	Cool, 4°C Det. on site	6 hrs[c]	424
Phenolics	500	G only	Cool, 4°C H_3PO_4 to pH < 4 1.0 g $CuSO_4$/l-	24 hrs	574

TABLE C-7 (continued)

Measurement	Vol. req. (ml)	Container	Preservation	Holding time[f]	Standard Method Number[g]
Phosphorus					
Ortho-phosphate, dissolved	50	P,G	Filter on site Cool, 4°C	24 hrs[d]	425
Hydrolyzable	50	P,G	Cool, 4°C H_2SO_4 to pH < 2	24 hrs[d]	
Total	50	P,G	Cool, 4°C	24 hrs[d]	
Total, dissolved	50	P,G	Filter on site Cool, 4°C	24 hrs[d]	
Residue					
Filterable	100	P,G	Cool, 4°C	7 days	208
Non-filterable	100	P,G	Cool, 4°C	7 days	
Total	100	P,G	Cool, 4°C	7 days	
Volatile	100	P,G	Cool, 4°C	7 days	
Settleable matter	1,000	P,G	None Req.	24 hrs	208
Selenium	50	P,G	HNO_3 to pH < 2	6 months	318
Silica	50	P only	Cool, 4°C	7 days	426
Specific conductance	100	P,G	Cool, 4°C	24 hrs[e]	205
Sulfate	50	P,G	Cool, 4°C	7 days	427
Sulfide	50	P,G	2 ml zinc acetate	24 hrs	428
Sulfite	50	P,G	Cool, 4°C	24 hrs	429
Temperature	1,000	P,G	Det. on site	None	212
Threshold odor	200	G only	Cool, 4°C	24 hrs	206
Turbidity	100	P,G	Cool, 4°C	7 days	214

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[a] More specific instructions for preservation and sampling are found with each procedure as detailed in the literature (25).

[b] Plastic or glass

[c] If samples cannot be returned to the laboratory in less than 6 hrs and holding time exceeds this limit, the final reported data should indicate the actual holding time.

[d] Mercuric chloride may be used as an alternate preservation at a concentration of 40 mg/l, especially if a longer holding time is required. However, the use of mercuris chloride is discouraged whenever possible.

[e] If the sample is stabilized by cooling, it should be warmed to 25°C for reading or temperature correction made and results reported at 25°C.

[f] It has been shown that samples properly preserved may be held for extended periods beyond the recommended holding time.

[g] The numbers in this column refer to the appropriate parts of the "Standard Methods for the Examination of Water and Wastewater, 14th edition, APHA-AWWA-WPCF, 1975.

- Sulfates.
- Total organic carbon.
- Nitrate-nitrogen.
- Total phosphorus.
- Methylene blue active substances (surfactants).
- Selected metals or toxic substances, where applicable.
- Indicator microorganisms.

Regulatory agencies may require fewer or more parameters than listed above, depending on the sensitivity of the aquifer being sampled and other factors.

C.4.5 Ground Water Monitoring in the Unsaturated Zone

The unsaturated soil zone is the soil located vertically between ground surface and the top of the water table. Collection devices installed in the unsaturated zone will collect samples of the leachate migrating down from the sludge amended surface soil to the ground water aquifer, and can provide early warning of potential future ground water contamination. Unsaturated zone monitoring is rarely required or used. Possible uses are for research and demonstration projects or occasionally for dedicated land disposal sites. The most commonly used devices to collect leachate are pressure-vacuum lysimeters. They are relatively inexpensive and fairly reliable. A typical pressure-vacuum lysimeter is shown in Figure C-2. In an optimum arrangement, lysimeters are installed at various depths in the unsaturated zone. Bentonite plugs are placed at the top and bottom of each hole during backfilling to prevent channeling of contaminated surface water directly to the lysimeter. Alternatively, the lysimeters can be installed horizontally into the soil or at angles along the edge of the site. There is some indication in literature that horizontal placement is better than vertical placement. The porous ceramic cup in each lysimeter should be surrounded by a slurry of wet, fine quartz which ensures hydraulic continuity with the surrounding soil.

After the lysimeters are in place, a vacuum is applied to the system and the tubes are clamped off. To collect leachate samples, the vacuum is released and the discharge tube is placed in a sample container. Air pressure is applied to the other tube which forces the leachate up the tube and into the sample container.

The degree to which the porous cup selectively filters various elements may pose a potential problem for collecting representative samples. Preliminary testing should be conducted to evaluate whether the parameter of concern is filtered out by the porous cup.

C.5 Surface Waters

Properly designed sludge-to-land application sites are generally located, constructed, and operated to minimize the chance of surface water runoff containing sludge constituents. For sites utilizing the

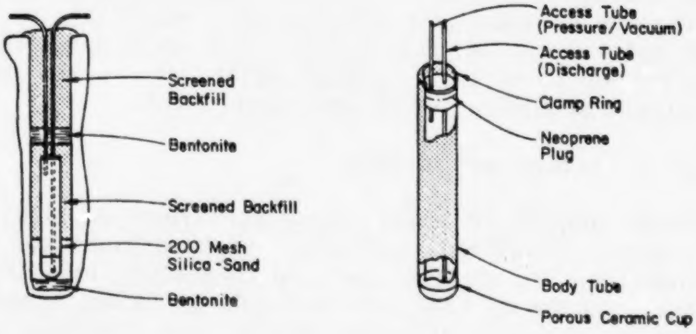

Figure C-2. Typical pressure/vacuum lysimeter for leachate monitoring.

agricultural utilization option at agronomic rates of sludge application, surface water monitoring is rarely required. Generally, surface water monitoring is done only in one, or more, of the following situations:

- Surface water runoff from the site is collected, stored, and discharged to surface waters outside the application area under an NPDES permit.
- The sludge application site is in close proximity to surface waters which are sensitive (e.g., drinking water supplies, swimming areas,etc.), and monitoring is required by the cognizant regulatory agency to ensure that migration of sludge constituents to these surface waters is not occuring.
- It is desirable for public acceptance purposes to moderate community concern about surface water quality impacts.

C.5.1 Surface Water Monitoring Procedures

Selection of surface water sampling stations, equipment, and procedures should follow a systematic plan. Surface sampling stations should be located in areas which represent the greatest potential for contamination. These points can be determined after examining the pathways available for runoff to enter a surface water body. Flow patterns and seasonal variations should be noted when applicable.

C.5.1.1 Rivers and Streams

Sampling stations should be established at stream sections where the water composition is relatively uniform. Such sections can be located on small- and medium-size streams, but are frequently impossible to find on large rivers. Where uniform sections can be found, sampling procedures may often be simplified to the extent that a single grab sample may be obtained that is representative of the stream composition in that general location.

C.5.1.2 Lakes and Reservoirs

A thorough study of water composition can be made by sampling along a three-dimensional grid pattern; samples can be collected at different depths at each grid intersection. A more economical approach is to sample a different depth along selected cross sections and sampling points. When only one sample is collected to define the average character of the lake or reservoir, it should be collected near the center of the water mass. However, a single sample is completely inadequate for a study of a lake of any size, and at best provides only an approximation of average water quality. To evaluate the quality of reservoir water for potential downstream users, the sampling site should be located at or near the point of discharge.

Surface water sampling equipment should be suited to the goals of a particular monitoring program. Sampling equipment and procedures can range from continuous or intermediate automated samplers to manual collection by filling a container by hand. Manual sampling is generally considered to be adequate.

C.5.2 Surface Water Sample Preparation

See Table C-7.

C.5.3 Surface Water Parameters

Generally, the parameters of concern in a surface water monitoring program are those which either may affect public health, or those which may contribute to eutrophication, e.g., nitrogen and phosphorus. An illustration of parameters which are often analyzed in surface water samples taken in connection with sludge application site(s) monitoring is shown in the following list:

- Fecal coliforms.
- Total P.
- Total N (Kjeldahl).
- Dissolved oxygen.
- BOD or TOC.
- Temperature.
- pH.
- Suspended solids.

C.6 Sludge

Virtually all POTW's which intend to apply sludge to land under one of the sludge utilization options covered by this manual will be required to routinely sample and analyze the sludge being applied. Among the many purposes for sludge monitoring are:

- To obtain baseline data on sludge physical and chemical characteristics prior to design of the sludge to land utilization system (see Chapter 3). This data is necessary to design virtually every component of the system, e.g., sludge transport, application site size, sludge application rates, etc.

- To provide records of the quantity of sludge constituents, e.g., nutrients, metals, etc., being applied to the sludge application site(s).

- To verify adequate sludge stabilization operations at the POTW.

- To satisfy regulatory agency requirements.

C.6.1 Sludge Sampling Frequency

The frequency of sludge sampling necessary will usually be set by the regulatory agency, and may vary from daily samples for a very large system to quarterly samples for a very small system. See Section 11.5.2 for a general discussion of factors involved in determining sludge sampling frequency.

Since concentrations of many constituents in sewage sludge from the same POTW vary significantly over time (see Appendix A), a single sample is generally not representative of sludge quality over time. Multiple samples should be taken to assure statistically valid estimates of sludge constituent concentrations. A typical simplified procedure is outlined below.

- Step 1: Take weekly composite samples for five consecutive weeks and analyze the constituents of concern (e.g., percent solids, nutrients, heavy metals, etc.) for each of the five samples.

- Step 2: Calculate the average concentration for each constituent by summing the sample concentrations and dividing by five.

- Step 3: Calculate the statistical variances to determine if there is a 95 percent probability that the average determined in Step 2 is within ±25 percent of the "actual" average. "Standard Methods for Examination of Water and Wastewater" (4) contains a section on precision and accuracy which details determination of 5 percent probability. The formula below can be used:

  Variance = (0.25 x (x-y)

  Where: x = the sum of the squares of the five weekly sample concentrations; and y = one-fifth the square of the sum of the five weekly sample concentrations.

- Step 4: Multiple 123.3 times the variance and divide the result by the square of the average calculated in Step 2. This provides a "testing number." If the "testing number" is below 5.00, then the average concentration calculated in Step 2 has statistically 95 percent probability.

  If the "testing number" is above 5.0, additional weekly composite sludge samples should be taken until an average concentration with 95 percent probability is obtained.

C.6.2 Sludge Sampling Location

The sludge samples should be representative of the sludge being applied to the application site (5). If sludge is being hauled directly from the POTW, and applied without intervening storage, sample may be composited at the POTW. However, if sludge is stored at an intermediate facility prior to field application, the sludge samples should be composited after withdrawal from the storage facility. Many sludge constituents usually increase, but ammonia nitrogen concentration decreases. Obviously, the best location for sludge sampling is at the sludge application site itself during application operations.

C.6.3 Sludge Sample Preservation

Sludge samples should be refrigerated at approximately 4°C immediately after collection, which provides adequate preservation for most types of sludge physical and chemical analyses for a period of up to 7 days, i.e., sufficient to obtain a weekly composite sample. Analysis for bacteria, parasite, etc., should be made as soon as possible, e.g., within 24 hours. If this is not possible, the samples may be frozen.

C.6.4 Sludge Parameters

The common analyses for sludge are as follows:

- Percent solids.
- Percent volatile solids.
- Ammonia nitrogen.
- Total nitrogen.
- Heavy metals (Zn, Ni, Cu, Pb, and Cd).
- Total phosphorous.

Other analyses may be performed routinely because of a specific sludge characteristic known to be significant or because of regulatory requirements. These may include:

- Chromium.
- Mercury.
- Arsenic.
- Various pesticides and other persistent organics.
- Phenols.
- Biological.

Table C-8 lists standard extraction methods for certain sludge elements. When the element is in solution, see Table C-3 for analytical methods.

C.7 References

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TABLE C-8
EXTRACTION METHODS FOR SLUDGES

Element	Method	Reference Number	Page
Nitrogen (N):			
Total N	Kjeldahl digestion	1	1164
N-ammonia	Extract with 2N KCl	1	1191
N-nitrate	Extract with 2N KCl	1	1191
N-nitrite	Extract with 2N KCl	1	1191
Phosphorus (P):			
Total P	Persulfate digestion	4	474
Organic P	Persulfate digestion	4	474
Inorganic P	Total P minus organic P	-	-
Carbon (C)			
Organic C	a) 1N $K_2Cr_2O_7$ b) concentrated H_2SO_4 c) water	1	1374
Total C	Digestion with 60:40 concentrated H_2SO_4/85% H_3PO_4	1	1350
Inorganic C	Digestion with concentrated H_2SO_4 and $FeSO_4 \cdot 7H_2O$	1	1386
Metals	Digest with HNO_3 + $HClO_4$	4	144

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APPENDIX D

CASE STUDY OF SLUDGE USE FOR RECLAMATION OF DISTURBED MINING LANDS IN VENANGO COUNTY, PENNSYLVANIA

The Venango County, Pennsylvania, demonstration project provides an example of a well-planned and managed reclamation project that used sludges from local small cities to reclaim a bituminous coal strip mine spoil bank that had been recontoured without topsoil replacement. The post-mining land utilization of the site was vegetation establishment to reduce soil erosion and sedimentation followed by natural succession leading to a mixed hardwood forest cover.

D.1 Site Location

The site was mined by a coal company in 1965, and is located in Irwin Township, Venango County, Pennsylvania. It was mined prior to the passage of the current surface mining regulations (PL 95-87) that require topsoil replacement. Three previous attempts were made by the coal company to reclaim the area using lime, commercial fertilizer, and seed; however, these efforts were unsuccessful and the site was essentially barren. Four ha (10 ac) of the approximate 40 ha (100 ac) area was selected for sludge application in a demonstration project. To maximize the value of the project, both liquid and dewatered sludges at a high and low rate were applied. After completion of the demonstration project, it is planned to continue to use sludge to complete reclaiming the remaining 36 ha (90 ac).

D.2 Preliminary Preparations

D.2.1 Pretreatment Soil Sampling

Twenty-one soil pits were excavated on the demonstration site with a backhoe to a depth of 90 cm (36 in). Each pit was used for the collection of soil samples and for the installation of suction lysimeters for percolate water sample collection. Three soil pits were excavated in each sludge treatment sub-plot and in an adjacent control. Soil samples were collected at the 0 to 15 (0 to 6 in) 15 to 30 (6 to 12 in), 30 to 60 (12 to 24 in), and 60 to 90 cm (24 to 36 in) depth for chemical analyses. For a site not being used as a demonstration, only 3 to 4 soil pits would be needed for monitoring purposes. Surface soil samples were collected from the area for initial soil pH to determine liming requirements, and the cation exchange capacity of the area.

D.2.2 Monitoring Instrumentation

A monitoring system was established as required in Pennsylvania, to determine the effects of the sludge applications on chemical and bacteriological quality of ground water and soil percolate, on the chemical properties of the soil, and on the vegetation.

Two suction lysimeters were installed in the excavated soil pits at the 90 cm (35 in) depth for the collection of percolate water samples. One was used specifically for the collection of percolate water for bacterial analyses (total and fecal coliform) and the other for routine chemical water quality analyses. Samples were collected bi-weekly for the first five months and then monthly thereafter. For non-demonstration, large-scale projects in Pennsylvania, only monthly sampling is required.

Three 15 cm (6 in) diameter ground water wells were drilled to monitor the effects of the sludge application on ground water quality. Ground water well sites were located by geologists of the Pennsylvania Department of Environmental Resources to collect samples upgradient and downgradient of the sludge application site. The depth of each well and the depth to the water level at the time of drilling was as follows:

Well No.	Total Depth (m)	Depth to Water Level (m)
1 (upgradient)	18.0	5.3
2 (downgradient)	17.8	3.3
3 (downgradient)	11.4	2.1

Metric conversion factor:

1 m = 3.281 ft.

Ground water well samples were collected on the same schedule as percolate water samples. Samples were collected with both a submersible pump and a Kemmerer water sampler. The pump was used to remove standing water and draw-down the well. After recovery, the pump was used to obtain a sample of fresh water in the well. For nondemonstration projects in Pennsylvania, only one downgradient ground water monitoring well is required.

Water samples were also collected from two lakes adjacent to the demonstration plots. The samples were analyzed for the same constituents as the soil percolate water samples.

D.2.3 Background Sludge Sampling

Sludge for the demonstration project was obtained from POTW's at the cities of Farrell, Franklin, and Oil City, Pennsylvania. Liquid sludge was obtained from Farrell and Oil City, and dewatered sludge from Franklin and Oil City. Sludge samples were collected from each plant and analyzed to determine the loading rates and acceptability of the sludges for land application. Analysis of the sludge constituents as they were applied to the site are presented in Tables D-1 and D-2.

TABLE D-1
CHEMICAL ANALYSIS OF DEWATERED SLUDGE APPLIED ON THE VENANGO COUNTY DEMONSTRATION PLOTS

		Range	
Constituent	Mean	High	Low
pH	7.9	8.2	7.7
	- - - - - ppm on dry weight basis - - - -		
Total P	4,624	6,327	2,701
No$_3$-N	46	52	40
NH$_4$-N	727	839	635
Organic N	12,188	14,612	9,990
Total N	12,962	15,500	10,768
Ca	9,970	12,699	3,805
Mg	2,082	3,108	590
Na	286	350	235
K	93	142	44
Al	6,133	8,641	1,208
Mn	1,651	2,703	285
Fe	29,709	44,561	5,912
Co	22	34	13
Zn	811	1,008	295
Cu	661	967	471
Pb	349	377	302
Cr	413	665	180
Ni	69	111	55
Cd	3.2	4.1	1.2
Hg	0.6	0.9	0.4
PCB	1.2	1.4	1.0

TABLE D-2
CHEMICAL ANALYSIS OF LIQUID DIGESTED SLUDGE APPLIED ON THE VENANGO COUNTY DEMONSTRATION PLOTS

Constituent	Mean	Range	
		High	Low
pH	6.8	7.0	6.6
	- - - - - ppm on dry weight basis - - - -		
Total P	5,883	7,293	4,819
No$_3$-N	1,780	3,869	528
NH$_4$-N	4,217	6,295	2,633
Organic N	20,509	25,021	18,010
Total N	26,506	35,185	21,750
Ca	39,726	63,836	26,344
Mg	6,689	12,051	4,707
Na	6,264	8,734	3,935
K	407	542	304
Al	19,545	42,083	6,667
Mn	808	1,022	531
Fe	28,517	34,460	20,909
Co	21	25	19
Zn	1,796	2,138	1,031
Cu	1,750	2,481	793
Pb	999	1,201	741
Cr	1,560	2,521	409
Ni	113	129	95
Cd	8.8	14.1	5.7
Hg	0.9	1.6	0.4
PCB	1.5	2.7	0.1

D.3 Site Preparation

Four 1-ha (2.5-ac) plots were laid out and marked for sludge application. Two of these plots received liquid digested sludge, the other two dewatered sludge.

D.3.1 Scarification

Prior to application, a portion of the demonstration area was scarified with a tractor and chisel plow. This was necessary because the surface spoil material had been compacted in the backfilling and leveling operation. In addition, the roughened surface would prevent runoff of sludge should an unusually heavy rainfall occur during the sludge application operation. The area to receive the dewatered sludge was completely scarified. However, the chisel plow dug up many large rocks and brought them to the surface. As a result, it was decided to scarify only the perimeter of the plots to receive liquid digested sludge, as a precaution against sludge runoff.

D.3.2 Liming

Analyses of surface soil samples indicated that the average soil pH was 3.9 (buffer pH 5.9) in the area to receive dewatered sludge. Therefore, agricultural lime was applied at the rate of 12.3 mt/ha (5.5 T/ac). This amount of lime was sufficient to raise the soil pH to 6.5. Liming is a Pennsylvania regulatory requirement and is necessary to immobilize the heavy metal constituents in the sludge and prevent them from leaching into the ground water.

Lime was also applied to one plot (1.0 ha; 2.5 ac) to receive liquid digested sludge. Average soil pH was 6.1 (buffer pH was 6.6). Lime was applied at the rate of 4.5 mt/ha.

D.3.3 Diversions and Berms

Diversion ditches were installed to prevent sludge runoff in the direction of the two lakes on the property. A berm was constructed on three sides of the dewatered sludge unloading and storage area to prevent any movement of sludge from the area and to prevent water running into the sludge unloading area from higher ground.

D.4 Sludge Application and Incorporation

Because of the diversity of waste treatment processes and the variation in concentration of constituents in the sludges, it was decided to mix the sludges on the site prior to application. Samples of the sludge mixture were collected as the sludge was applied on the demonstration plots. Six composite samples were collected as the dewatered sludge was applied and five composite samples were collected as the liquid sludge was applied. The results of these analyses are given in Table D-1 (dewatered sludge) and Table D-2 (liquid digested sludge). Average solids content for the liquid digested sludge was 3 percent and for the dewatered sludge was 52 percent. Average total nitrogen content was 1.3 percent for the dewatered sludge and 2.7 percent for the liquid digested sludge.

Results of the sludge analyses were used to calculate the amounts of selected nutrients and trace elements applied in the various application rates. These amounts are given in Table D-3.

A comparison of the maximum sludge application rate with the EPA and PDER recommendations is given in Table D-4. The amounts of trace metals applied in the sludge were below the PDER recommendations with the exception of copper. The amount of copper applied slightly exceeded the PDER recommendation but was well below the EPA recommendation.

The commercial fertilizer equivalents of the various sludge application rates are given in Table D-5. The highest sludge application rate would be equivalent to applying 10 mt/ha (4.5 T/ac) of an 11-9-0 commercial fertilizer. The value of the sludge as a commercial fertilizer substitute is quite obvious.

D.4.1 Liquid Digested Sludge

During May 17-23, 1977, liquid digested sludge was hauled in tank trucks (19,000 to 26,000 l; 5,020 to 6,869 gal) from the cities of Farrell and Oil City. At the site the liquid sludge was emptied from the tankers into a temporary small holding pond with a plastic liner. The pond provided a means for mixing the two sludges. A vacuum tank liquid manure spreader with a 5,700 l (1,506 gal) capacity pumped the sludge from the holding pond and spread it on the plots (Figure D-1). One-half of the demonstration area received liquid sludge at an application rate of 155 m^3/ha (equivalent to 11 dry mt/ha; 4.9 T/ac). The other half received sludge at the rate of 103 m^3/ha (equivalent to 7 dry mt/ha; 3.1 T/ac). It was not possible to apply the liquid digested sludge at the proposed design rate of 20 mt/ha because infiltration was restricted, and no more sludge could be applied without the threat of producing surface runoff.

D.4.2 Dewatered Sludge

During May 18-21, 1977, dewatered sludge was transported by coal trucks from the cities of Franklin and Oil City. A total of 588 wet mt (647 T) of sludge was transported to the site. The sludge from the two treatment plants was unloaded at the site and mixed with a front-end loader prior to application with a farm manure spreader (Figure D-2). One-half of the demonstration site (1.0 ha; 2.5 ac) received an application of dewatered sludge at the rate of 90 mt/ha (40.0 T/ac) and the other half (1.0 ha; 2.5 ac) received 184 mt/ha (82.1 T/ac). Sludge spreading was completed by May 25, 1977. On May 26, 1977, a tractor with a 6.4-mt (7.04 T) disc attachment was used to incorporate the sludge into the surface 10 cm (4 in) of spoil material (Figure D-3).

TABLE D-3
AMOUNTS OF SELECTED NUTRIENTS AND TRACE ELEMENTS APPLIED BY EACH SLUDGE APPLICATION ON THE VENANGO COUNTY DEMONSTRATION PLOTS

Constituent	Sludge Application Rate in Metric Tons/Hectare			
	184	90	11	7
	- - - - - - - - - - - kg/ha - - - - - - - - - - -			
Total N	2,388	1,165	284	187
P	918	448	63	41
K	18	9	4	2
Cu	129	63	21	13
Zn	147	72	21	13
Cr	74	36	16	10
Pb	55	27	10	7
Ni	12	7	1	0.7
Co	3	2	0.2	0.1
Cd	0.6	0.2	0.09	0.07
Hg	0.09	0.04	0.01	0.007

Metric conversion factors:

1 kg/ha = 0.89 lb/ac.
1 mt/ha = 0.446 T/ac.

TABLE D-4
COMPARISON OF TRACE METAL LOADINGS AT THE VENANGO COUNTY DEMONSTRATION PROJECT WITH EPA AND PDER RECOMMENDATIONS (13)

Constituent	Sludge Application Rate 184 mt/ha	Recommendations	
		EPA (CEC 5-15)*	PDER
	- - - - - - - - - - - kg/ha - - - - - - - - - - -		
Cu	129	250	112
Zn	147	500	224
Cd	0.6	10	3
Pb	55	1,000	112
Ni	12	250	22
Cr	74	NR†	112
Hg	0.09	NR†	0.6

* Average CEC of site ranged from 11.6 to 15.2 meq/100g.
† No recommendations given by EPA.

Metric conversion factors:

1 mt/ha = 0.446 T/ac
1 kg/ha = 0.89 lb/ac.

TABLE D-5
COMMERCIAL FERTILIZER EQUIVALENTS OF THE SLUDGE APPLICATION RATES IN VENANGO COUNTY

Sludge Application Rate	Fertilizer Equivalent (Fertilizer Formula)			
	Amount	N	P_2O_5	K_2O
mt/ha	kg/ha	kg/ha (%)	kg/ha (%)	kg/ha (%)
184	22,400	2,388 (11)	2,103 (9)	21 (0)
90	11,200	1,165 (10)	1,026 (9)	11 (0)
11	2,240	284 (13)	143 (6)	6 (0)
7	2,240	187 (8)	95 (4)	2 (0)

Metric conversion factors:

1 mt/ha - 0.446 T/ac
1 kg/ha = 0.89 lb/ac.

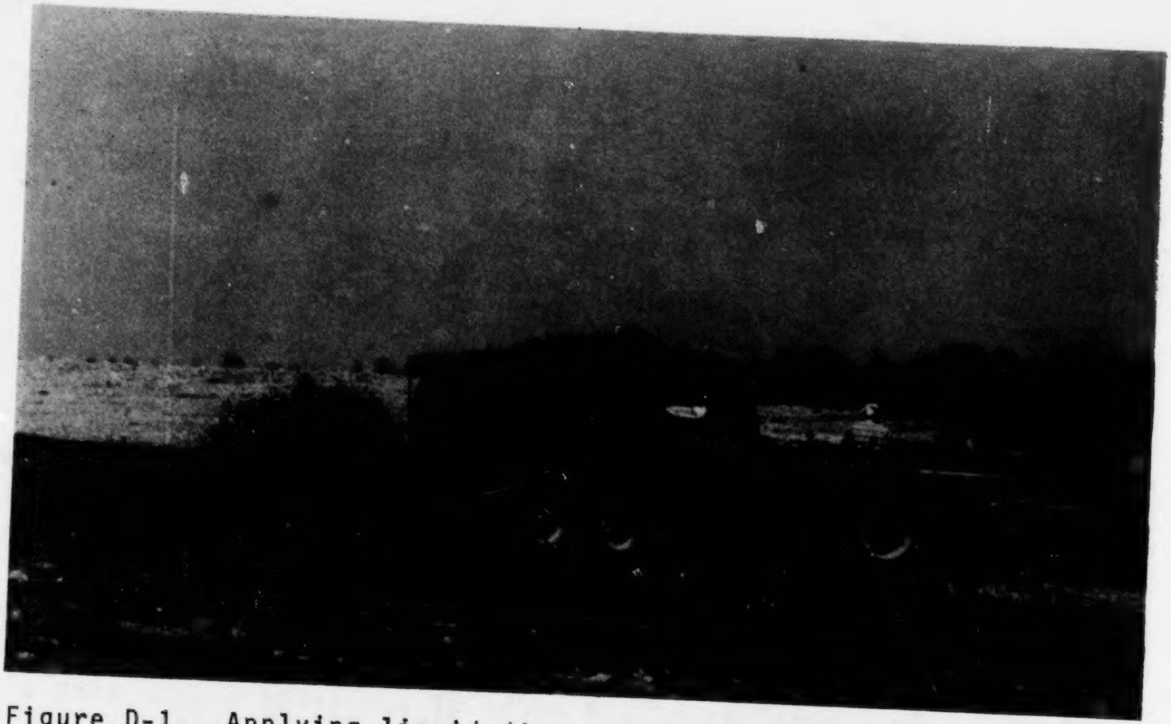

Figure D-1. Applying liquid digested sludge with a vacuum liquid manure spreader on a bituninous strip mine spoil bank.

Figure D-2. Applying composted sludge to a strip mine site after top soil replacement and liming.
(Courtesy of Dr. William Sopper)

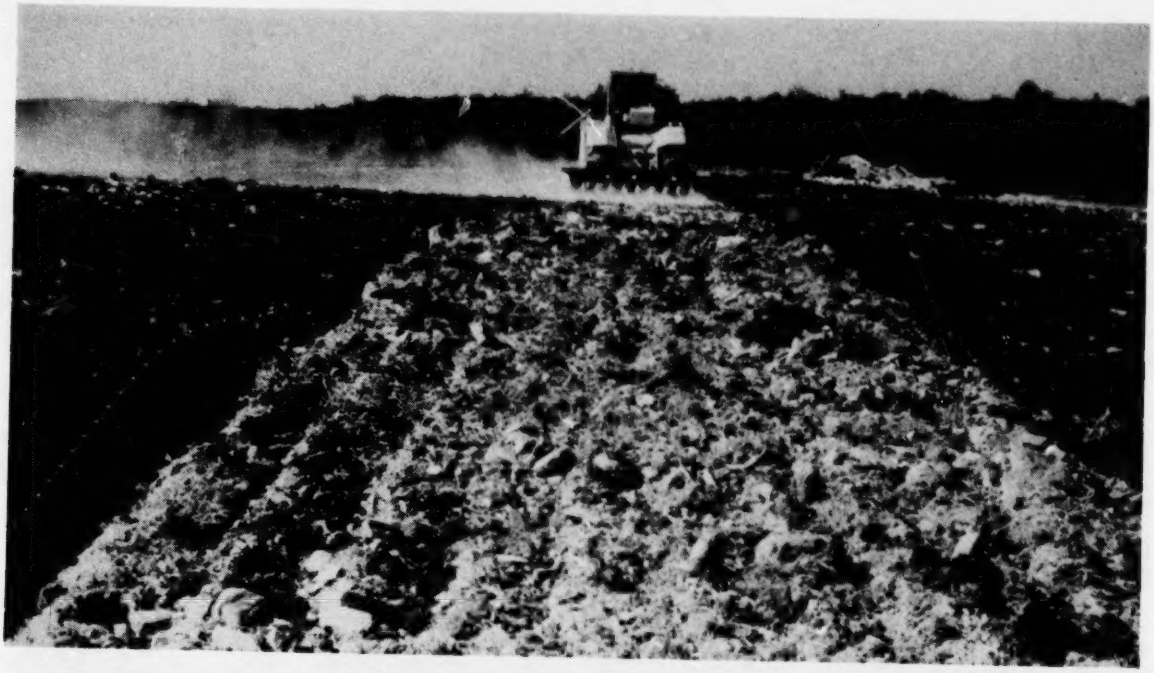

Figure D-3. Incorporation of 184 mt/ha of dewatered sludge with a disc on an abandoned strip mine site in Pennsylvania. (Courtesy of Dr. William Sopper)

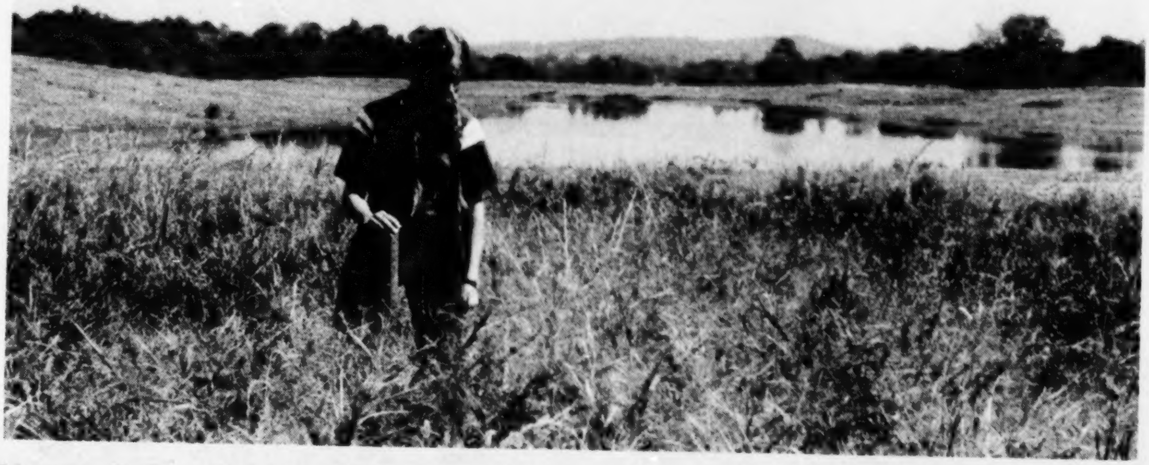

Figure D-4. Portion of same site as shown in Figure three months after sludge incorporation and seeding. Note complete lush vegetative cover. Within five years the grass species shown was almost completely replaced by permanent legume species.
(Courtesy of Dr. William Sopper)

D.5 Seeding and Mulching

During May 27-31, 1977, the sludge-treated areas were broadcast seeded with a mixture of two grasses and two legumes. The seed mixture used was:

	kg/ha
Kentucky-31 tall fescue	22
Pennlate orchardgrass	22
Penngift crownvetch	11
Birdsfoot trefoil	11
Total	66

Metric conversion factor:

1 kg/ha = 0.89 lab/ac

This seeding mixture was selected so that the two grass species would germinate quickly, and provide a complete protective cover the first year allowing time for the two legume species to become established and develop into the final vegetative cover.

The seed of the two grass species was mixed together and applied with a tractor-mounted seeder. The seed of the two legume species was innoculated, mixed together, and broadcast seeded with hand-carried whirlybird seeders. On large-scale operations, the entire seed mixture can be broadcast seeded at one time with a tractor-mounted seeder. Immediately after seeding, the entire 4-ha (10 ac) demonstration site was mulched with straw and hay at the rate of 3.8 mt/ha (1.7 T/ac), although mulching is normally not necessary unless required by state regulations.

D.6 Monitoring Program

Some of the monitoring data is presented here as an example of the type of information which are collected on reclamation projects using sludge in Pennsylvania.

D.6.1 Vegetation Growth Responses

Vegetation growth responses were evaluated at the end of each growing season. The results of these measurements are given in Table D-6. All sludge treated areas had a complete cover of vegetation by August 1977 (Figure D-4), 3 months after sludge application. Both vegetation height growth and dry matter production continually increased during the following 4-year period with no additional sludge additions.

TABLE D-6
VEGETATION HEIGHT GROWTH AND DRY MATTER PRODUCTION AT THE VENANGO COUNTY DEMONSTRATION SITE

Sludge Application	Height			
	1977	1978	1979	1980
mt/ha	cm			
7	29	37	52	55
11	32	30	43	48
90	34	41	41	49
184	35	52	44	58
	Dry Matter Production			
	kg/ha			
7	6,349	9,537	18,538	34,403
11	7,731	8,654	17,141	26,664
90	4,757	7,409	13,327	26,060
184	6,013	9,336	11,322	31,189

Metric conversion factors:

1 mt/ha = 0.446 T/ac
1 cm = 0.3937 in
1 kg/ha - 0.89 lb/ac.

During the first two growing seasons, the two grass species were the dominant vegetation type on all sludge treated plots. During the second growing season the two grasses (tall fescue and orchardgrass) produced prolific seed heads. Seed heads were collected from 30 cm (12 in) square plots and weighed. Results indicated a seed production ranging from 168 to 336 kg (370 to 741 lb) of seed per ha (150 to 300 lb/ac). By the third growing season, the two legume species were well developed and had become the predominant vegetation cover on the plots treated with liquid digested sludge and the limed dewatered sludge treated plots. The unlimed dewatered sludge treated plots were still vegetated primarily by the two grass species with only a few sparse patches of legumes.

Samples of the individual grass and legume species were collected at the end of each growing season for foliar analyses. Results for tall fescue and birdsfoot trefoil for the highest sludge application rate are given in Table D-7 for 1977 to 1980. Foliar trace metal concentrations generally decreased over the 4-year period. Overall, the trace metal concentrations were well below the suggested tolerance levels. These levels represent the level at which a yield reduction might occur and do not represent levels at which severe toxicity occurs. There were no phytotoxicity symptoms observed for any vegetation on the sludge treated areas.

TABLE D-7
AVERAGE CONCENTRATION IN UG/G OF TRACE METALS IN THE FOLIAR SAMPLES COLLECTED FROM THE 184 mt/ha PLOT AT THE VENANGO COUNTY DEMONSTRATION SITE

Species	Year	Cu	Zn	Cr	Pb	Co	Cd	Ni
Tall Fescue	1977	9.4	44.4	0.8	4.5	1.5	0.20	9.8
	1978	8.6	44.4	0.8	4.5	1.6	0.41	3.7
	1979	9.2	72.5	0.5	1.8	0.6	0.08	2.5
	1980	3.5	41.9	1.1	3.8	1.8	0.73	7.3
Birdsfoot Trefoil	1977	13.9	95.9	1.0	7.4	2.1	0.43	6.3
	1978	7.7	30.4	0.3	8.5	3.0	0.07	4.8
	1979	9.2	41.5	1.7	1.8	0.3	0.04	6.3
	1980	8.2	45.3	1.9	4.5	1.4	0.08	6.5
Suggested Tolerance Level (11)		150	300	2	10	5	3	50

In general, the vegetation cover improved over the five growing seasons (1977-1981) following sludge application. No deterioration in vegetation quality or yield was measured or observed. In comparison, the remainder of the site, not treated with sludge, remained barren.

For a non-demonstration project, this type of information on vegetation yield and quality would only have to be collected for the first year following sludge aplication.

D.6.2 Spoils

To evaluate the effects of the sludge treatment on the chemical properties of the spoil, samples were collected at various locations and depths at the end of each year. Results of spoil pH for the highest sludge application (184 mt/ha; 82 T/ac) area are given in Table D-8. Surface spoil pH generally increased over the 5-year period following sludge application. Results indicate that the lime and sludge applications did raise the spoil pH significantly and that the higher pH was maintained. Under Pennsylvania guidelines, surface spoil samples must be collected at the end of the first and second year following sludge application to document that the pH has not dropped below pH 6.5. Should the pH be below this level, lime must be applied to raise it to at least 6.5.

Spoil samples were also analyzed for trace metals. A comparison of trace metal concentrations before and after sludge was applied is given in Table D-9. Even at the highest sludge application rate (184 mt/ha;

TABLE D-8
RESULTS OF SPOIL pH FOR THE 185 mt/ha PLOT AT THE VENANGO DEMONSTRATION SITE

Spoil Depth (cm)	Spoil pH				
	Before Sludge	1977	1978	1979	1981
0-15	3.8	6.2	6.7	7.3	6.7
15-30	3.8	4.2	4.6	5.1	5.1

Metric conversion factors:

1 mt/ha = 0.446 T/ac
1 cm = 0.3937 in.

TABLE D-9
ANALYSES OF SPOIL SAMPLES FOR EXTRACTABLE TRACE METALS ON THE 184 mt/ha PLOT AT THE VENANGO COUNTY DEMONSTRATION SITE

Time of Sampling	Spoil Depth	Cu	Zn	Cr	Pb	Co	Cd	Ni
	cm	ug/g						
Before sludge applied	0-15	2.5	2.9	0.2	0.5	0.7	0.02	1.1
	15-30	3.0	2.4	0.1	0.6	0.7	0.02	1.0
	30-60	3.7	3.6	0.2	0.9	1.0	0.03	1.6
Four months after sludge applied	0-15	10.8	7.7	0.4	3.5	1.3	0.07	0.9
	15-30	4.0	2.0	0.1	1.3	0.2	0.01	0.4
	30-60	4.9	2.9	0.1	1.9	0.3	0.01	0.5
Eighteen months after sludge applied	0-15	8.8	7.7	0.2	2.3	1.2	0.02	1.2
	15-30	2.5	1.7	<0.1	1.3	0.5	0.01	0.7
	30-60	1.8	1.8	<0.1	1.5	0.5	0.01	0.7
Normal range soil (12)		2-100	10-300	5-3,000	2-200	1-40	0.01-7.0	10-1,000

Metric conversion factors:

1 mt/ha = 0.446 T/ac
1 ug = 2.2 x 10^{-9} lb.

82.1 T/ac) the trace metal concentrations in the surface spoil (0-15 cm; 0 to 6 in) were only slightly increased. In general, the trace metal concentrations in the spoil were all extremely low in comparison to published normal ranges for soils. For a non-demonstration project, soil samples need only to be taken one year after the sludge application.

D.6.3 Water Quality

D.6.3.1 Soil Percolate Water Quality

Results of the analyses of soil percolate water at the 90 cm (36 in) depth for the highest sludge application and the control plot are given in Table D-10. Average monthly concentrations of NO_3-N in the percolate during the summer months in the first year (1977) on the plots treated with the highest applications of dewatered sludge were only slightly above potable water standards (10 mg/l). The highest monthly average was 13.0 mg/l for August. Percolate NO_3-N concentrations were surprisingly low during May and June immediately following the sludge application. This was probably due to the fact that rainfall during this period was below normal. As a result, there was little opportunity for leaching of nitrogen from the sludge to occur. By October, after development of a complete vegetative cover, the concentrations of NO_3-N in the percolate decreased to levels below 10 mg/l. Concentrations of NO_3-N in the percolate remained at low levels throughout 1978 to 1981.

TABLE D-10
RESULTS OF ANALYSES FOR TRACE METALS AND NITRATE-NITROGEN FOR SOIL PERCOLATE AT THE 90-CM DEPTH FROM THE VENANGO COUNTY DEMONSTRATION SITE

Sludge Application Rate	Year*	Cu	Zn	Cr	Pb	Co	Cd	Ni	NO_3-N
mt/ha		- -	- - - -	- - - -	- - - mg/l	- - -	- - -	- - -	- -
0	1977	0.63	2.75	0.23	0.07	0.67	0.005	1.37	1.8
	1978	0.14	1.20	0.05	0.10	0.22	0.002	0.33	0.7
	1979	0.10	0.68	0.05	0.05	0.12	<1.001	0.26	0.7
	1980	0.08	0.90	0.06	0.07	1.10	0.001	0.22	0.8
184	1977	0.24	5.91	0.04	0.05	1.50	0.011	2.82	7.3
	1978	0.04	1.16	<0.01	0.08	0.19	0.002	0.26	0.5
	1979	0.07	0.87	0.02	0.05	0.20	0.001	0.34	<0.5
	1980	0.02	0.51	0.01	0.03	0.06	0.001	0.11	0.6
EPA Drinking Water Standard		1.00	5.00	0.05	0.05		0.010		10.0

* Values represent the mean of all samples collected from the plot for the year.

Average monthy concentrations of NO_3-N in the percolate at the 90 cm (36 in) depth on the areas treated with liquid digested sludge were slightly higher than those measured on the dewatered sludge plots. The highest concentration was 33.9 mg/l on the 11 mt/ha (5 T/ac) plot and occurred during the first month (June 1977) following sludge application. These higher concentrations were probably due in part to the fact that the NO_3-N concentrations was higher in the liquid digested sludge (1,780 mg/l) than in the dewatered sludge (46 mg/l) and nitrate-nitrogen in the liquid sludge is more susceptible to leaching prior to vegetation establishment. Concentrations of NO_3-N in percolate water started to increase almost immediately after sludge application. By August 1977, after development of a complete vegetative cover, concentrations of NO_3-N in percolate decreased to levels well below 10 mg/l and remained at low levels throughout the study period.

Results of the analyses for dissolved trace metals at the 90 cm (36 in) depth for the highest sludge application as well as the control plot are also given in Table D-10.

Results indicate that percolate water quality met EPA drinking water standards with only a few exceptions. During the first 3 months in the first year following sludge application, the concentrations of Zn and Ni significantly increased and exceeded drinking water standards at the highest sludge application rate. Concentrations of Cr and Pb slightly exceeded drinking water standards on both the control and sludge-treated plots. During the second (1978) and third (1979) years, only concentrations of Pb exceeded drinking water standards at the highest sludge applications. These concentration increases were minimal and pose no threat to human or animal health. Note that the average monthly concentrations of Pb on the control plot also exceeded potable water standards during the study period (1977-1981).

Total and fecal coliform analysis were conducted on all soil percolate water samples collected during the period May 1977 through October 1979. No fecal coliform colonies were observed for any sample.

D.6.3.2 Ground Water Quality

Ground water samples were collected biweekly from monitoring wells to evaluate the effect of the sludge applications on ground water quality. Results of these analyses are given in Table D-11. Well No. 1 was drilled as a control outside the area of influence of the sludge applications. Ground water flow under the dewatered sludge-treated area is toward Well No. 2 located approximately 11 meters downslope from the plot. Results indicate that the high application of dewatered sludge did not significantly increase the concentration of NO_3-N in ground water. Concentrations of NO_3-N were below EPA limits for potable water (10 mg/l) for all months sampled. It also should be noted that the average depth to ground water in Well No. 2 was only 3 m (9.8 ft).

TABLE D-11
GROUND WATER ANALYSES FOR TRACE METALS AND NITRATE-NITROGEN FOLLOWING SLUDGE APPLICATION AT THE VENANGO COUNTY DEMONSTRATION SITE

Well No.	Year*	Cu	Zn	Cr	Pb	Co	Cd	Ni	NO_3-N
		(mg/l)							
Well No. 1 (Control)	1977	0.22	4.13	0.01	0.14	3.19	0.006	3.23	1.4
	1978	0.23	2.02	0.01	0.19	1.04	0.002	1.00	<0.5
	1979	0.17	1.48	0.03	0.13	0.58	0.002	0.50	<0.5
	1980	0.04	0.84	0.05	0.10	0.59	<0.001	0.51	0.6
Well No. 2 (Dewatered Sludge) (184 mt/ha)	1977	0.10	3.39	0.03	0.09	2.12	0.001	2.67	1.1
	1978	0.14	3.29	0.01	0.20	1.16	0.002	1.26	<0.5
	1979	0.18	1.83	0.03	0.13	1.92	0.001	0.97	<0.5
	1980	0.03	1.01	0.05	0.10	0.82	0.001	0.72	0.7
EPA Drinking Water Standard		1.00	5.00	0.05	0.05		0.010		10.0

* Values represent the mean of all samples collected from each well for the year.

Results of analyses of ground water samples for trace metals during the four years after sludge was applied are also given in Table D-11. There appears to be no significant increase in any of the trace metal concentrations in Well No. 2, which was influenced by the sludge applications. Average annual concentrations were below EPA drinking water standards. All ground water samples collected during the period July 1977 to July 1981 were also analyzed for coliforms. No fecal coliform colonies were observed for any sample.

APPENDIX E

CASE STUDY OF SLUDGE APPLICATION TO AGRICULTURAL LAND AT SALEM, OREGON

E.1 Introduction

Salem, Oregon, initiated a formal program of sludge application to agricultural land in 1976, known as the BIOGRO program. The system has been highly successful, and recycles to local farmland approximately 90 to 95 percent of all sludge generated by the city's Willow Lake POTW. Information utilized in this case study was obtained from Reference (1), and personal communications with Ms. Dixi Druery, Director of the Salem BIOGRO Program (2), and Mr. Tom Fisher, Environmental Specialist, Oregon State Department of Environmental Quality (DEQ), Salem, Oregon (3).

E.2 Sludge Treatment, Quantity, and Characteristics

The Willow Lake POTW utilizes both trickling filter (old treatment chain) and activated sludge (1976 treatment chain additions) treatment processes. Primary and secondary raw sludge is combined, thickened, and anaerobically digested in heated digesters. Secondary digesters store the sludge prior to distribution for agricultural application. A small percentage (5 to 10 percent) of the digested sludge is lagooned at the POTW when sludge hauling is not possible due to weather or other factors. Salem is a major fruit and vegetable processing center, and wastewater and sludge volumes increase significantly during the processing months of June through September.

Annual digested sludge volume in 1982 was 121,000 m^3 (32 million gal), of which 110,000 m^3 (29 million gal) were applied to agricultural land. The average dry solids content of the sludge is approximately 2.3 percent, so the dry sludge solids applied to agricultural land was approximately 2,500 mt (2,800 T) in 1982.

Typical digested sludge characteristics are shown in Table E-1, based on samples taken in early 1983. The sludge is low in metals content and high in N content. The high N content is due to the addition of ammonia nitrogen during the treatment process because the raw sewage contains a high percentage of food processing wastes which are deficient in nutrients. The characteristics of the sludge vary through the year, and daily sampling and analysis of sludge is done as described in Section E.5.

E.3 Sludge Application to Farmland

In 1982, sludge was applied to approximately 1,200 ha (3,000 ac) of local agricultural land. Application sites are located as far as 32 km (20 mi) from the POTW, but the majority are located within an 11-km (7-mi) radius of the POTW. At virtually all sites, the sludge is applied only once per year.

TABLE E-1
CHARACTERISTICS OF DIGESTED SLUDGE AT SALEM, OREGON, WILLOW LAKE POTW*

Constituent	Concentration†	Constituent	Concentration
Total solids, %	2.5	Fe, mg/kg	21,000
pH	7.3	Pb, mg/kg	230
Total N, %	10.3	Ba, mg/kg	720
NH_3-N, %	5.9	Cr, mg/kg	60
P, %	2.0	Mg, mg/kg	200
K, %	0.96	Ca, mg/kg	12,200
Zn, mg/kg	980	Na, mg/kg	3,000
Cu, mg/kg	470	As, mg/kg	<0.1
Ni, mg/kg	43	Co, mg/kg	8
Cd, mg/kg	7		

* All constituents except pH reported on a dry weight basis.

† Personal communication based on samples in early 1983.

Sludge is applied at calculated agronomic rates based on N needs of the crop (see Chapter 6). Sludge application rates average approximately 3.4 mt/ha (1.5 T/ac), and vary from 2.2 mt/ha (1.0 T/ac) to 6.3 mt/ha (2.8 T/ac) (dry weight), depending on the N uptake of the crop grown and the N content of the sludge applied. The N applied varies from approximately 89 kg/ha (100 lb/ac) to 267 kg/ha (300 lb/ac). The following section presents the method of calculation used to determine sludge application rates.

The crops to which sludge is applied are predominantly grains, grasses, pasture, and silage corn. Sludge is also applied to seed crops, Christmas tree farms, commercial nurseries, and filbert orchards. No sludge is applied to fruit and vegetable crops which will be processed by local fruit and vegetable processing plants. The DEQ requires an 18-month waiting period after sludge application before planting of fruits and vegetables which may be eaten raw.

E.3.1 Determination of Sludge Application Rates

Each sludge application site is investigated prior to obtaining DEQ approval for sludge application. If the site is approved by DEQ, an approval letter is issued stipulating the conditions under which sludge can be applied. Criteria and guidelines used by DEQ are summarized below.

E.3.1.1 Soils Limitations

The soils at the proposed application site are sampled by the city of Salem; generally, one soil sample for every 2 ha (5 ac) of site area. Soil samples are taken at depths of 0 to 30 cm (0 to 12 in), 30 to 60 cm (12 to 24 in), and 90 to 120 cm (36 to 48 in). Analyses are made for cation exchange capacity (CEC), and pH.

The SCS drainage classification is used by DEQ to determine when sludge may be applied during the year. For poorly drained soils, sludge can generally only be applied during the period from April 15th through October 15th. For well drained soils, sludge can be applied anytime except during or immediately after seasonal rainstorms. Other soil drainage classifications fall between these allowable scheduling extremes.

CEC is used to limit cumulative metal loadings added by sludge application. Table E-2 lists these cumulative metal loadings. Note that if soil pH is less than 6.5 (as it is in most of the Salem area), then cumulative Cd addition is limited to 4 kg/ha (4.5 lb/ac), regardless of soil CEC. Since the sludge generated by Salem is very low in metals, application sites generally have a life well over 25 years, based on cumulative metal loadings derived from annual sludge applications.

TABLE E-2
CUMULATIVE SLUDGE METAL LOADINGS
FOR AGRICULTURAL LAND, SALEM, OREGON

CEC (meq/100 g)	Pb	Zn	Cu	Ni	Cd*
	kg/ha (lb/ac)				
<5	400 (450)	200 (225)	100 (112)	40 (45)	4 (4.5)
5-15	801 (900)	400 (450)	200 (225)	80 (90)	8 (9.0)
>15	1,602 (1,800)	801 (900)	400 (450)	160 (180)	16 (18)

* If soil pH is below 6.5 maximum Cd limitation is 4 kg/ha (4.5 lb/ac) regardless of soil CEC.

E.3.1.2 Crop Nitrogen Need Limitations

The annual sludge application rate to a particular site is based on the N needs of the crop being grown (see Chapter 6 for a discussion of agronomic application rate). The DEQ uses two formulas, depending on whether (1) the sludge is applied and left to dry on the soil surface, or (2) the sludge is incorporated into the soil within 48 hours. The two formulas are presented below.

Surface Application Without Soil Incorporation:

$$G = \frac{120{,}000 \times N}{S\,[50M + 20\,(T-M)]} \qquad \text{(E-1)}$$

where:

G = Sludge application rate, in gal/ac

N = Annual N need of crop, in lb available N/ac

S = Solids content of the sludge, expressed as a percent

M = inorganic N (NH_3-N and NO_2-N) content of the sludge, dry weight basis, expressed as a percent

T = Total Kjeldahl N content of the sludge, dry weight basis, expressed as a percent

Surface Application with Incorporation into Soil Within 48 Hours:

$$G = \frac{120{,}000 \times N}{S\ (85M + 15T)} \qquad \text{(E-2)}$$

Where all terms are identical to the formula in Equation (E-1) above.

As an example of the use of the formulas above, assume the following:

- Sludge solids (S) = 2.3%.
- Crop available nitrogen need (N) = 200 lb/ac/year.
- Inorganic nitrogen (M) = 3%, dry weight basis.
- Total nitrogen (T) = 6%, dry weight basis.

Given the conditions above, the sludge application rate, if the sludge is surface-applied and not incorporated into the soil, is calculated as follows:

$$G = \frac{120{,}000 \times 200}{2.3\ [(50 \times 3) + 20(6 - 3)]}$$

$$= 49{,}700 \text{ gal/ac of sludge application}$$

Given the conditions above, the sludge application rate, if the sludge is incorporated into the soil within 48 hours, is calculated as follows:

$$G = \frac{120{,}000 \times 200}{2.3\ [(85 \times 3) + (15 \times 6)]}$$

$$= 30{,}250 \text{ gal/ac of sludge application}$$

E.3.2 Application Site Constraints and Guidelines

The State DEQ investigates each proposed agricultural sludge application site prior to giving approval for sludge application. The investigator makes his recommendations on a case-by-case basis. However, general guidelines/requirements are as follows:

- Minimum distance of sludge application to domestic wells = 61 m (200 ft).
- Minimum distance of sludge application to surface water = 15 m (50 ft).
- Minimum rooting depth (effective depth of soil) = 0.61 m (2 ft).
- Minimum depth to ground water at time that sludge is applied = 1.22 m (4 ft).
- Minimum distance of sludge application to public access areas varies with the method of sludge application, as follows:

  - If sludge is incorporated into soil = 0
  - If sludge is not incorporated into soil = 30.5 m (100 ft)
  - If sludge is pressure-sprayed ("big gun" type sprayer) over the soil = 91 to 152 m (300 to 500 ft).

  Sludge application is not approved close to residential developments, schools, parks, etc.

- Minimum slope is largely left to the investigator's discretion. Where no surface waters are endangered, slopes as high as 30 percent have been approved. Generally, however, the maximum allowable slope is 12 percent, and in cases where sensitive surface waters are nearby, maximum slopes may be held to 7 percent or less.

E.4 Sludge Transport and Application Methods

Sludge is hauled and applied to agricultural land virtually year around in the Salem BIOGRO program. All hauling is done by a fleet of four tanker trucks with a useful capacity of 20,000 l (5,500 gal) each. Application to specific sites is scheduled on the basis of (1) farmer requests as a function of crop planting and harvesting patterns; (2) period of sludge application to the specific site allowed by DEQ, based on site soil drainage (see Section E.3.1.1); (3) weather (e.g., sludge is not applied during rainstorms); and (4) proximity of application sites to each other and to the POTW.

In general, pasture and grassland receive sludge applications during the winter months, and agricultural land growing seasonal crops receives sludge during the summer months, before planting or after harvesting. Since the BIOGRO program has been in effect for 7 years, past experience enables management to anticipate which sites will require sludge during various times of the year.

Sludge is usually applied by the haul trucks themselves, using gravity discharge and a splash plate (see Chapter 10) to distribute the sludge at an average rate of approximately 1,700 l/min (450 gpm) (Figure E-3). The haul trucks are not equipped with flotation tires, so the application site soil must be dry and firm to allow application with the haul trucks. If the application site soil is wet, or otherwise unsuitable for direct truck access, then a traveling big gun sprinkler is used to spray the sludge onto the application site. In this procedure, the haul truck is parked as close to the application site as practical and connected sequentially to a short discharge hose, a portable pump (Figure E-1), portable aluminum pipe (if necessary), a 200-m (600-ft) long hose, and a big gun sprinkler (Figure E-2). The traveling big gun sprinkler is capable of spraying liquid sludge in a 37-m (120-ft) radius at a rate of 1,360 l/min (360 gpm).

City employees do all of the sludge hauling and spreading. Three permanent full-time drivers are used year around, and two additional temporary drivers are added during the summer months when sludge volume and distribution activity is increased.

E.5 Monitoring Program

E.5.1 Sludge Monitoring

Each truck load of sludge leaving the POTW is sampled. Samples are composited at the end of each day, and the composite sample is analyzed for total solids, total N, and NH_3-N. A weekly sludge sample is also composited, and the weekly composite sample is analyzed for total solids, total N, NH_3-N, Cd, Cu, Pb, Ni, Zn, chromium, P, and K. Monthly sludge samples are analyzed for all of the constituents listed in Table E-1. The daily composite sludge sample analysis is used to determine sludge application rates required for various sites to meet the agronomic N requirement of the crop being grown. The less frequent sludge analyses are used to monitor the cumulative metal loadings being applied to each site. Records are kept of the annual sludge application to each site, including quantities per acre of dry solids, total N, ammonia N, and the various metals applied.

E.5.2 Soil Monitoring

As described in Section E3.1.1, prior to receiving sludge, each site undergoes soil sampling and analysis. During the early years of the BIOGRO program, the city routinely analyzed the sludge-amended soil yearly or every 3 years. Results showed virtually no change in soil chemical and physical characteristics, so the city no longer routinely monitors soils at sludge application sites. Many farmers, however, routinely have their soils tested by laboratories as a prudent agricultural practice.

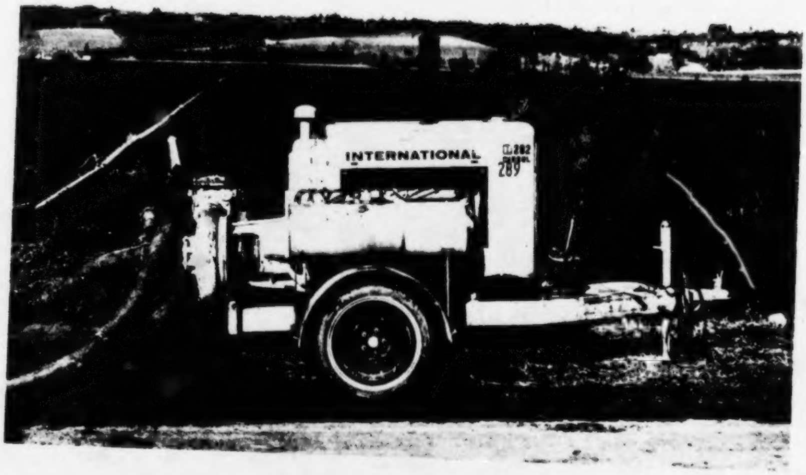

Figure E-1. Portable sludge pump (1).
(Note: City also uses propane powered Ford engine and Cornell pump which has been very satisfactory).

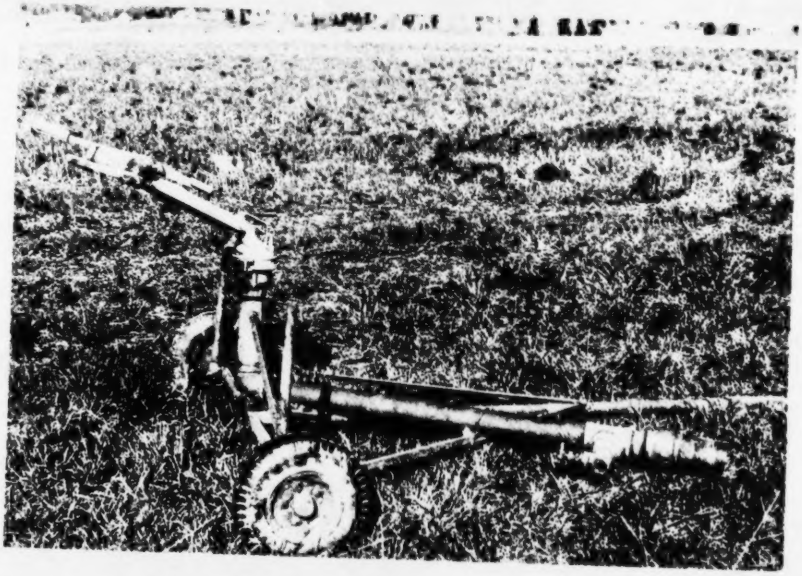

Figure E-2. Big gun sprinkler (1).
(Note: City also uses a self-propelled unit).

Figure E-3. BIOGROW sludge haul truck distributing sludge to farmland (EPA photo).

E.5.3 Ground Water Monitoring

During the early years of the BIOGRO program, ground water from wells on or within 150 m (500 ft) of sludge application sites was sampled and analyzed both before and after application. The constituents monitored were NO_2-N, TDS, coliform, Mg, As, and methylene blue activated substances (MBAS). Since results showed no significant changes in ground water quality over a period of 3 years, the ground water monitoring program has been gradually reduced. Selected wells are now sampled approximately every 3 years to check if any ground water degradation is occurring.

The city of Salem and the Oregon DEQ report that background levels of nitrate N were very high in ground water samples obtained from many of the wells in the area north of the POTW. These high nitrate N levels are thought to be due to the soil characteristics in this area and the application of commercial fertilizers over long periods. To avoid future claims of ground water degradation, the BIOGRO program does not apply sludge to areas north of the POTW.

E.5.4 Crop Sampling

The BIOGRO program conducted some limited crop tissue sampling and analysis during the initial years of the program. Constituents analyzed included Bo, Cd, Cu, Mg, Ni, Zn, As, Pb, Mo, and Se. Results showed no significant difference between crops grown on sludge-amended soils and control crops. Routine crop sampling and analysis is no longer conducted.

E.5.5 Surface Water Sampling

Application sites are selected to avoid the possibility of surface water contamination, and no surface water monitoring is routinely conducted.

E.6 References

1. CH_2M Hill. BIOGRO Program, Organic Solids Reuse, Willow Lake Wastewater Treatment Plant, Salem, Oregon, June 18, 1976.

2. Personal Communication with Ms. Dixi Druery, Manager of BIOGRO Program, Salem, Oregon, May 1983.

3. Personal Communication with Mr. Tom Fisher, Environmental Specialist, Oregon State Department of Environmental Quality, Salem, Oregon, May 1983.

APPENDIX F

CONVERSION FACTORS
(Metric to U.S. Customary)

Metric			U.S. Customary Unit	
Name	Symbol	Multiplier	Abbreviation	Name
Centimeter(s)	cm	0.3937	in	inches
Cubic Meter	m^3	8.1071×10^{-4} 35.3147 264.25	acre-ft ft^3 Mgal	acre-foot cubic foot million gallons
Cubic Meters Per Day	m^3/d	2.6417×10^{-4}	Mgal/d	million gallons per day
Cubic Meters Per Hectare	m^3/ha	1.069×10^{-4}	Mgal/acre	million gallons per acre
Degrees Celsius	°C	1.8(°C) + 32	°F	degrees Fahrenheit
Gram(s)	g	0.0022	lb	pound(s)
Hectare	ha	2.4711 0.004	acre mi^2	acre square miles
Kilogram(s)	kg	2.205	lb	pound(s)
Kilograms Per Hectare	kg/ha	0.0004	tons/acre	tons per acre
Kilograms Per Hectare Per Day	kg/ha/d	0.893	lb/acre/d	pounds per acre per day
Kilograms Per Square Centimeter	kg/cm^2	14.49	lb/in^2	pounds per square inch
Kilometer	km	0.6214	mi	mile
Kilowatt	kW	1.34	hp	horsepower
Liter	L	0.0353 0.264	ft^3 gal	cubic foot gallon(s)
Liters Per Second	L/s	0.035 22.826 15.85 0.023	ft^3/s gal/d gal/min Mgal/d	cubic feet per second gallons per day gallons per minute million gallons per day
Metric Tonne	mt	1.10	T	ton (short)
Metric Tonnes Per Hectare	mt/ha	0.446	T/ac	tons per acre
Meter(s)	m	3.2808	ft	foot (feet)
Meters Per Second	m/s	2.237	mi/h	miles per hour
Micrograms Per Liter	ug/L	1.0	ppb	parts per billion
Milligrams Per Liter	mg/L	1.0	ppm	parts per million
Square Centimeter	cm^2	0.155	in^2	square inch
Square Kilometer	km^2	0.386	mi^2	square mile
Square Meter	m^2	10.76	ft^2	square foot

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